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In-field Welding and Coating Protocols

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Executive Summary

Gas Technology Institute (GTI) and Edison Welding Institute (EWI) created both laboratory and in-field girth weld samples to evaluate the effects of weld geometry and hydrogen off-gassing on the performance of protective coatings. Laboratory made plate welds were used to tightly control geometric differences and in-field welds were created to mimic real world welding conditions and hydrogen off-gassing rates. These welds were then coated and tested with accelerated corrosion techniques to evaluate the coatings' effectiveness.

Simulated girth welds investigated geometric effects on the performance of a liquid applied coating. Welds were created, coated, and testing in a salt-fog environment to accelerate corrosion. Undercuts up to 0.03 inches were found to have no significant effect on a coatings' resistance to corrosion. On the contrary the undercut tended to add to the coating thickness and therefore increased corrosion resistance. Increasing cap height of a weld was found to thin the coating making it more susceptible to chipping but no more susceptible to corrosion. If applying proper coating procedures, especially surface profiling, the weld geometries investigated here had no strong negative effects on a liquid applied two part epoxy coating's performance. Since fusion bonded epoxy (FBE) coatings are applied in a different manner, these results cannot be extended from liquid to FBE coatings. If the FBE provides the same wetting of the undercut and similar coating thickness on the cap height one would expect similar results.

In-field welds were created to test the effects of hydrogen off-gassing on coating performance. Two different welding mediums were used, one with a high hydrogen content and one with a low hydrogen content. These different welds were then held for 2 or 5 hours to vary the amount of time allowed for hydrogen off-gassing and then coated in either FBE or a liquid 2 part epoxy. All other variables were held constant. Cross-sectional analysis of coated 24-inch diameter pipes showed no increase of voids above the welded area, indicating there was little off-gassing in these samples. Cathodic Disbondment Testing, per ASTM G-95, was performed to evaluate the coating's adhesion properties. No detectable adhesion differences were found that could be attributed to the hydrogen off-gassing from the weld, instead the results were more dependent on the coating thickness. Within the scope/boundary of the completed research, a hold time of two hours is sufficient to minimize any hydrogen off-gassing effects.

Within the parameters of the in-field welds and simulated welds no major detrimental effects were found from hydrogen off-gassing and weld geometries. However, the higher cap height did make coatings more susceptible to damage when handling. This confirms previous GTI research which indicated that coatings often accrue damage during handling.

GTI and EWI, taking into consideration the survey and testing results produced a recommendation to be distributed to various stakeholders in the pipeline industry. The summary document to be distributed is located in the *Recommendation* section of this report.

List of Acronyms

Acronym	Definition
GTI	Gas Technology Institute
EWI	Edison Welding Institute
FBE	Fusion Bonded Epoxy
AWS	The American Welding Society
ANSI	American National Standards Institute
GMAW	Gas Metal Arc Welding
SMAW	Shielded Metal Arc Welding
API	American Petroleum Institute
ASME	American Society of Mechanical Engineers
PHMSA	Pipeline and Hazardous Materials Safety Administration.
DOT	Department of Transportation

List of Standards

Standard	Title
ASME B31.4	<i>Pipeline Transportation Systems for Liquid Hydrocarbons and Other Liquids</i>
ASME B31.8	<i>Gas Transmission and Distribution Piping Systems</i>
ASTM D 610	<i>Standard Practice for Evaluating Degree of Rusting on Painted Steel Surfaces</i>
ASTM D 3359	<i>Standard Test Methods for Measuring Adhesion by Tape Test</i>
ASTM D 4285	<i>Standard Test Method for Indicating Oil or Water in Compressed Air</i>
ASTM D 4417	<i>Standard Test Methods for Field Measurement of Surface Profile of Blast Cleaned Steel</i>
ASTM D 4541	<i>Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers</i>
ASTM D 6677	<i>Standard Test Method for Evaluating Adhesion by Knife</i>
ASTM G 62	<i>Standard Test Methods for Holiday Detection in Pipeline Coatings</i>
ASTM G 95	<i>Standard Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method)</i>
API 1104	<i>Welding of Pipelines and Related Facilities</i>
AWS D1.1	<i>Structural Welding Code – Steel</i>
NACE No. 2/ SSPC-SP 10	<i>Near-White Metal Blast Cleaning</i>
NACE No. 8/ SSPC-SP 14	<i>Industrial Blast Cleaning</i>
NACE RP0105	<i>Liquid-Epoxy Coatings for External Repair, Rehabilitation, and Weld Joints on Buried Steel Pipelines</i>
NACE RP0188	<i>Discontinuity (Holiday) Testing Of Protective Coatings</i>
NACE RP0274	<i>Standard Recommended Practice High-Voltage Electrical Inspection of Pipeline Coatings</i>
NACE RP0287	<i>Standard Recommended Practice - Field Measurement of Surface Profile of Abrasive Blast Cleaned Steel Surfaces Using a Replica Tape</i>
NACE RP0390	<i>Standard Recommended Practice - Maintenance and Rehabilitation Considerations for Corrosion Control of Existing Steel Reinforced Concrete Structures</i>
NACE RP0490	<i>Standard Recommended Practice - Holiday Detection of Fusion-Bonded Epoxy External Pipeline Coatings of 250 to 760 μm (10 to 30 mils)</i>
SSPC VIS1	<i>Guide and Reference Photographs for Steel Surfaces Prepared by Dry Abrasive Blast Cleaning</i>

Introduction

Coatings are designed to protect steel pipelines from environmental effects, and work in conjunction with cathodic protection to provide long term corrosion resistance. The cost and safety impact of pipeline coating failures can be enormous. Typically, premature coating failures occur with field applied coatings. Main line coatings, applied under factory conditions, rarely fail. The primary reasons for failure include lack of coordination between the welding, surface preparation, and coating steps. Including improper or inadequate surface preparation of the weld zone, or coating application procedures not designed to work with the specified weld features. This project addresses the interactions between in-field welding and field applied pipe coatings.

During pipeline construction, a protective coating is applied after weld joints are completed and inspected. The ability of the pipe to resist corrosion depends on the integrity of the coating system, as well as the way in which the welds are made. Welding factors that can affect coating integrity include the geometry of the weld, and diffusion of hydrogen from the weld.

Geometric factors that affect coating integrity include cap height and reinforcement angle (i.e., the intersecting angle between the weld cap and the pipe surface at the weld toe). Excessive weld cap height or reinforcement height, as shown in Figure 1, can cause "tenting," a gap between the coating and pipe surface of tape coatings and heat shrink sleeves, which can lead to corrosion adjacent to the weld.



Figure 1: Excessive Weld Cap

Shielded metal arc welding (SMAW) is a common pipeline welding process used by 50% of survey respondents; utilizes cellulosic-coated electrodes that produce high levels of diffusible hydrogen in a solidified weld. This hydrogen diffuses out of the weld (i.e., out-gassing) for many hours after weld completion. Since the rate of this diffusion is temperature dependent, coating systems that use heat (e.g., fusion bonded epoxy) can accelerate hydrogen diffusion, resulting in blistering of the coating. An alternative technology, mechanized gas metal arc welding (GMAW), is a low hydrogen welding process that would reduce the likelihood of blistering as a result of off-gassing.

At the present time, interactions between pipeline welding contractors and applicators of field applied pipe coatings are minimal at best. The pipeline industry lacks comprehensive field testing procedures for welding and coating of steel pipeline joints, hot taps, or other maintenance items. As a result, the industry generally uses the known best practices from internal experience and written standards. Root cause analysis of coating failures are often not performed when an owner/operator experiences coating failures.

In response to this coating issue, in 2005 GTI completed the first phase of a multi-year field applied coating study (Figure 2) to determine how several field applied girth weld coating systems perform under various environmental and soil conditions, with FBE as the mainline coating. Over 50 coating systems were applied to over 500 pipeline joints on different size pipes, exposed to different service temperatures, and placed in service for different time frames. The results represent the "baseline performance" of nearly every major field applied coating and will be the starting point to assess field welding and coating improvements (Figure 3). In addition, identical testing began in 2004 on pipes coated with three layer polyethylene (PE) as the mainline coating.



Figure 2: GTI Applied Coating Study



Figure 3: Corrosion at Weld Coating Holiday

Edison Welding Institute (EWI) has completed numerous programs pertaining to the diffusion of hydrogen from pipeline girth welds, the development and application of semi-automatic and mechanized GMAW welding procedures/equipment for pipeline girth welding, and the installation of hot tap branch connections and repair sleeves.

Corrosion is one of the root causes of pipeline accidents and injuries. Improved and coordinated in-field welding and coating practices will help prevent:

- Pipeline corrosion
- Loss of pipeline integrity
- Loss of product
- Loss of life
- Environmental disasters

Proper coordination between the in-field welding and coating steps may also reduce rework and cost of a maintenance and/or installation project, while increasing the performance and lifetime integrity of the joints, hot taps, and repair sections. It is anticipated that the results of this project can be used to improve communications between pipeline welding contractors, pipeline operating companies, and coating applicators in the field. The results could also be used to develop or improve industry standards. To help facilitate these changes, EWI and GTI participate in relevant standards setting committees to help accelerate the acceptance process for improved protocols and procedures.

Project Overview

The scope of this project is to evaluate current industry standards and practices regarding pipeline welding and coating operations. Through experiments, potential issues that could lead to premature coating failures can be identified. The general approach of the project is outlined below.

1.1 Research Current In-field Welding and Coating Practices

To evaluate current procedures and practices EWI and GTI reviewed current industry standards and documented the commonality between them. Additionally, a survey was conducted of various operators to evaluate which standards are utilized in both welding and coating operations. The survey and literature review was used to create an overall summary of current industry practices and identify potential problem areas. The summary document from this work is contained in the *Survey and Literature Review* section.

1.2 Evaluate Weld Geometry's Effect on Coating Performance – Small Scale Welds

Weld geometry is controlled by various standards aimed at producing a structurally sound weld. There are little to no controls of weld geometry for the purpose of applying protective coatings. GTI and EWI created simulated girth welds to gauge the effects of different weld geometries on coatings performance. The geometries of primary interest were weld height and undercut depth. To perform the investigation, EWI created well controlled variances of these geometries in laboratory welds. GTI then applied coatings to the welds and developed a test method to investigate the resistance of the coatings to corrosion. Section *Appendix D: Simulated Girth Welds – Data* contains the details of the welds, experimentation, and results.

1.3 Evaluate Hydrogen Off-gassing's Effect on Coating Performance – In-field Welds

Hydrogen off-gassing from a welding area was identified as a possible source of coating failures if the coating was applied too soon after weld completion. Hydrogen exiting the welded area can cause bubble or voids within the coating. This can weaken or damage the coating making it more susceptible to failure. GTI and EWI created and coated girth welds using industry partners to evaluate the susceptibility of a coating to hydrogen off-gassing from a welded area. The time between weld completion and coating operations was varied to establish a minimum hold time before coatings could be applied. The weld completed by GTI, EWI, and industry partners were then tested at GTI to establish what effects there were from hydrogen off-gassing on coating performance. The complete report of these welds and tests are contained in the *Hydrogen Off-gassing Test - In-Field Welds* section of this report.

1.4 Provide Recommendations

Upon completion of the literature review and experimental work, GTI and EWI created recommendations to be submitted to industry standards. These recommendations concisely summarize the results of the projects and are being used to disseminate the project finding to relevant stake holders. This summary document is located in the *Recommendation* section of this report.

Survey and Literature Review

2.1 Welding Requirements

The welding section is a combination of pipeline welding requirements and the industry survey conducted by EWI and GTI as part of this project. Several welding defects can decrease the probability of a successful field applied pipeline coating. These defects include, but are not limited to, weld undercut, weld reinforcement height, weld spatter, and the weld leg length (for fillet welds). Many industry standards have acceptability limits for such weld defects, however they are more aimed at welder workmanship and not coating the pipeline.

75% of the survey respondents use either SMAW or GMAW as the preferred welding process for mainline welding or in-service welding applications (e.g., repair sleeves). The requirements outlined in welding considerations are applicable to both welding processes. A full explanation of the welding terms contained in this report is located in *Appendix A: Welding Terminology*. The below sections summarize the results from the literature review and the survey results. The full survey results are contained in *Appendix B: Survey Questions and Results*.

2.2 Butt Weld Requirements

2.2.1 Weld Undercut

60% of the survey respondents use visual inspection to determine the extent of weld undercut and if the weld undercut is acceptable. The most commonly referenced welding standards for determining the acceptable amount of weld undercut were American Petroleum Institute (API) 1104,¹ American Society of Mechanical Engineers (ASME) B31.4,² and ASME B31.8.³ It is important to note that both ASME B31.4² and ASME B31.8³ refer to API 1104¹ for the weld acceptance criteria. The API 1104¹ acceptance criteria also mirrors the acceptance criteria of many of the pipeline company's in-house acceptance standards. Since the majority of respondents use similar requirements, it is assumed that the undercut requirements for API 1104¹ can be considered the most common undercut requirement for most pipeline applications. Table 1 contains a summary of the API 1104¹ butt weld undercut acceptance criteria.

Table 1: API 1104¹ Butt Weld Undercut Acceptance Criteria

Butt Weld Undercut Depth	Butt Weld Undercut Length
> 0.031 in. or > 12.5% of wall thickness; whichever is smaller	Not Acceptable
> 0.016 in. but ≤ 0.031 in. or > 6% but ≤ 12.5% of wall thickness; whichever is smaller	2 in. in a continuous 12 in. weld or one-sixth the weld length; whichever is smaller
≤ 0.016 in. or ≤ 6% of wall thickness; whichever is smaller	Acceptable, regardless of length

2.2.2 Weld Reinforcement Height

Similar to undercut, the majority of the survey respondents use visual inspection to assess the weld reinforcement height for acceptability. The same standards referred to for undercut requirements were also referenced by the most of respondents to define weld reinforcement height requirements (ASME

B31.4² and ASME B31.8³ refer to API 1104¹). Over 80% of respondents cited a maximum weld reinforcement height, since it is assumed that the weld will not be under filled. There were two responses that indicated that there should be a minimum reinforcement height. Comparing the API 1104¹ requirements to the survey responses shows a preferred weld reinforcement height in the range of 0.031 in. to 0.063 in. (0.8 mm to 1.6 mm). There were allowances for larger weld reinforcement heights (not preferred).

2.2.3 Weld Spatter

All but 7% of the survey responses use visual inspection to determine the acceptability of weld spatter. There were no criteria outlined in any of the reviewed standards except that the weld area should be clean. Over three quarters of the respondents stated that spatter is not allowed. One respondent reported that the pipe should be cleaned in preparation for the coating step, but no details were provided in the response.

2.3 Fillet Welds Requirements

2.3.1 Weld Undercut

Three quarters of the survey responses state that fillet welds are visually inspected for undercut. The following standards were used API 1104,¹ ASME B31.4,² and ASME B31.8.³ Additional comments indicate that typical in-house requirements tend to be stricter for fillet welds than for butt welds; however, no details were given to quantify the stricter requirements. Similar to the butt weld undercut summary, it was assumed that the most common industry practice is to apply API 1104¹ undercut requirements to fillet welds (see Table 1).

2.3.2 Weld Reinforcement Height

Fillet welds are primarily visually inspected to determine the weld reinforcement height acceptability using API 1104,¹ ASME B31.4,² and ASME B31.8.³ Like many other criteria, the major standard used to determine acceptability was API 1104¹ followed by the ASME standards. There was an increase in the number of respondents that use American Welding Society (AWS) D1.1⁴ as the reference standard for fillet weld bead reinforcement height as compared to the number of respondents that use the butt weld reinforcement height criteria in API 1104¹. This may be due to the fact that API 1104¹ does not have a fillet weld reinforcement height acceptance criteria, whereas AWS D1¹ does have weld contour requirements for fillet welds that are related to the weld face of the fillet weld (as shown in Table 2).

Table 2: AWS D1.1⁴ Fillet Weld Reinforcement Acceptability Criteria

Fillet Weld Reinforcement Height
$\leq 1/6$ in. (2 mm) For Fillet Weld Faces $\leq 5/16$ in. (8 mm)
$\leq 1/8$ in. (3 mm) for Fillet Weld Faces $> 5/16$ in. (8 mm) and < 1 in. (25.4 mm)
$\leq 3/16$ in. (5 mm) for Fillet Weld Faces ≥ 1 in. (25.4 mm)

The fillet weld reinforcement height acceptability requirement is more relaxed than the reinforcement height acceptability requirement for butt welds. Comparing the reinforcement heights in Table 2 and the survey responses, the preferred weld reinforcement height for fillet welds was determined to be 0.118 in. (3 mm).

2.3.3 Weld Spatter

The weld spatter requirements for fillet welds were similar to the butt weld requirements; all weld spatter should be removed after the weld is completed.

2.3.4 Weld Leg Length

All but one of the survey respondents indicated that visual inspection was used to determine fillet weld length acceptability referencing API 1104,¹ ASME B31.4,² and ASME B31.8.³ These standards state that the fillet welds should have equal leg lengths or the difference in the fillet weld leg sizes should be less than 0.118 in. (3 mm).

2.3.5 Summary of Welding Requirements

Table 3 contains a summary of the preferred butt and fillet welding quality requirements based on a combination of pipeline industry standards and common industry practices.

Table 3: Weld Protocol Weld Quality Requirements

	Butt Weld	Fillet Weld
Undercut	<i>Maximum Undercut Limit</i> 0.031 in. (0.8 mm) <i>Preferred Undercut Limit</i> 0.016 in. (0.4 mm)	<i>Maximum Undercut Limit</i> 0.031 in. (0.8 mm) <i>Preferred Undercut Limit</i> 0.016 in. (0.4 mm)
Weld Reinforcement Height	<i>Acceptable Range</i> 0.031 in. to 0.063 in. (0.8 mm to 1.6 mm)	<i>Acceptable Range</i> 0.078 in. to 0.197 in. (2 mm to 5 mm) <i>Preferred</i> 0.118 in. (3 mm)
Spatter	None	None
Weld Leg Size		<i>Leg Difference</i> 0 in. to 0.118 in. (0 mm to 3 mm)

2.4 Coating Requirements

The coating section of the protocol is a combination of pipeline welding requirements and the industry survey conducted. (see *Appendix B: Survey Questions and Results*). In the survey, respondents were asked about coating failures and required preparation. Many described various types of failures including disbondment, cracking, blistering, and mechanical damage of coatings. Most companies use an industry standard that requires all welding slag and spatter to be removed and the area around the weld to be grit blasted prior to coating. Many respondents have seen failures as a result of high cap height and spatter especially on FBE coatings; however, weld reinforcement height is only part of the issue. Weld geometry plays a part in overall coating performance as it can lead to coating thinning and stress points. To date no quantifiable correlation exists between weld geometry and general coating failures.

2.4.1 Materials Storage

In the various specification used by different survey respondents, a common requirement is that coating materials be stored in their original containers with their original labels visible and readable. Storage conditions should be as specified by the manufacturer's data sheet and used within its shelf life as defined by the manufacturer.

2.4.2 Surface Preparation

All the standards used recognize that surface preparation is critical to any coating application. This includes both the cleaning of the surface as well as generating a proper surface profile to increase bonding. The survey indicated that companies use a variety of coating specific industrial standards for coating application and surface preparation. These include various NACE [RPO490, RPO188, RPO287,

RPO105, RPO274, and RPO394], ISO and API standards. The following points are the combined recommendations across many coating system standards. This information does not substitute for a proper coating specification with relevant references for the specific application.

2.4.3 Surface Preparation Pre-Cleaning

Visible deposits of oil or grease should be removed before grit blast cleaning in accordance with SSPC-SP1 Solvent Cleaning. Any Surface Reacted Surface Attached Salts (SRSAS) should be removed by an approved solvent in accordance to SSPC-SP 14 and rinsed thoroughly with de-ionized water. Any sharp features, splatter and excessive weld cap, on the area to be coated that could result in a holiday should be removed by hand filing or another approved method. There is little information contained in the common standards that identifies what constitutes sharp features or excessive weld cap.

2.4.4 Compressed Air

Air used for abrasive blasting, spray application, and cleaning should be free of oil and water. The coating applicators should perform a blotter test, in accordance with ASTM D 4285, at the nozzle or conventional air spray paint gun prior to starting operations for the day, to verify the purity of the air.

2.4.5 Surface Grit Blasting

Critical to any coating's adhesion is the proper surface profile of the base material. This is described in many standards and can be coating specific, but the survey indicates the NACE #2 or SSPC SP10 specifications are often used as references. These standards require the removal of material such as weld splatter, sharp edges, or rust bloom. This is followed by grit blasting to obtain a "near white" metal finish on the surface to be coated. Depending on weather conditions, the pipe may need to be preheated above the dew point to prevent water condensation on blasted areas. Another alternative is the use of dehumidification technology.

The blast material should be clean from any contaminants and create a profile of 2-4 mils, coating dependent. An inspection of the profile should be performed using various standards SSPC-VIS 1, ASTM D 4417, or NACE RP0287, see Figure 4. Any surface found to be outside the acceptable surface profile needs to be re-blasted until it meets the requirements.



Figure 4: Near white grit blasting visual standard

To facilitate proper coating protection the field applied coating and mill applied coating should overlap. A strip of the mill applied coating, 4 inches wide, should be "feathered or tapered" and roughened for proper bonding to the field applied coating. Any loose mill coating material should be removed and care should be taken to not damage any mill applied coating during blasting. Additional precautions should be taken to prevent blast material from entering nearby valves and fittings.

2.4.6 Coating Application

Prior to applying the coating all blasting residues and dust should be removed from all surfaces. Again, the compressed air used for cleaning should be free of oil and water. If any rust bloom or other defects appear between blasting and coating, the surface must be re-blasted until the "near white" surface is re-obtained. Blasted surfaces should be coated or primed the same day as the blasting. Coating operations must be sufficiently far from blasting operations to prevent contamination. Additional considerations must be made when inclement weather is present.

All field applied coatings should be applied in a manner consistent with the manufacturer's product data sheet. When a conflict exists between a standard or data sheet, the more strict provision should be followed. For mixed liquids, partial kits should not be used, and all mixing should follow manufacturer's directions. Field applied coatings should be applied to only clean, dry surfaces that are in their specified state of surface preparation. Surfaces that show signs of oxidation, rust bloom, or other deterioration should be re-blasted to the original specified cleanliness and surface profile before coating application.

All field applied coatings should be applied in a uniform and continuous film; free of blisters, holidays, runs, sags, wrinkles, air or gas entrapments, and other defects.

2.4.7 Coating Inspection

After the coating application and cure are completed the coating should be inspected. A coating's adhesion, hardness, and thickness should be examined. A method approved by the owner should be used, such as ASTM D 6677. Any defects found, such as coating delamination, are considered a failure and cause for coating reapplication. Hardness can be evaluated on a similarly prepared sample or with a portable tester directly on the pipe. The hardness value should fall inside the manufacture's specification. Thickness measurements should be taken and recorded by an owner approved method. Passing measurements must fall within the coating's recommended specifications. A thinner or thicker section of coating requires measuring nearby areas within 6 inches and averaging the measurements. Measurements outside of the max and min must be reported to the owner, who will make a decision on pass, fail, repair, or recoating.

Holiday inspection should also occur after the coating is fully cured. Inspection based off of ASTM G 62 or NACE RPO274 should be carried out over the entire coated area. Any holidays found must be repaired or the coating stripped and reapplied.

Coating repairs should consist of only manufacture's approved methods. This often includes using the original coating material on a dry, clean, and rough surface with sufficient overlap.

2.4.8 Backfill

After the coating is cured following manufacture instructions, it should be backfilled in a careful manner. Extra care should be taken to prevent rocks and debris from striking the coating.

2.5 *Summary of Literature Review and Survey*

The primary reasons for coating failures include lack of coordination between the welding, preparation, and coating steps, including improper or inadequate surface preparation of the weld zone, or coating application procedures not designed to work with the specified weld features. At the present time, interactions between most pipeline welding contractors, applicators of field pipe coatings are minimal at best. Steps should be taken to have meetings and pre-job conferences to verify the responsibilities of each party.

Based on the results of the literature search and survey, the draft welding and coating protocol can be summarized as follows:

- Prior to beginning work, a meeting should be held to identify areas of responsibility and timing.
- The most common acceptable range of undercut depth for both butt and fillets welds is 0 in. to 0.031 in. (0.0 mm to 0.8 mm).
- The most common acceptable range of butt weld reinforcement height is 0.031 in. to 0.063 in. (0.8 mm to 1.6 mm).
- All welding spatter, weld slag, and rust bloom must be removed prior to coating.
- All oil and debris must be removed from the air supply and pipe surface.
- Surface must be grit blasted to a proper profile of 2-4 mils, unless otherwise noted by coating manufacturer.
- Coating application should take place the same day as grit blasting, making sure that no rust has formed.
- Cured coatings must be inspected to see if it meets proper specifications.
- Coating application conditions must follow manufacture's recommendation.
- Approved Inspectors can identify and fix possible coating problems.

Weld Geometry Tests – Simulated Girth Welds

The goal of the small scale simulated girth weld tests is to investigate the effectiveness of a protective coating when applied to welds configured with varying geometries. The primary geometric differences explored were "cap height" and "undercut." Figure 5 illustrates cap height, which refers to the height of the weld bead above the substrate material. Undercut is a valley in the substrate material located at the weld toe. There are currently no standard procedures to test these differences on coating performance. GTI first established a procedure before testing the simulated girth welds created by EWI.

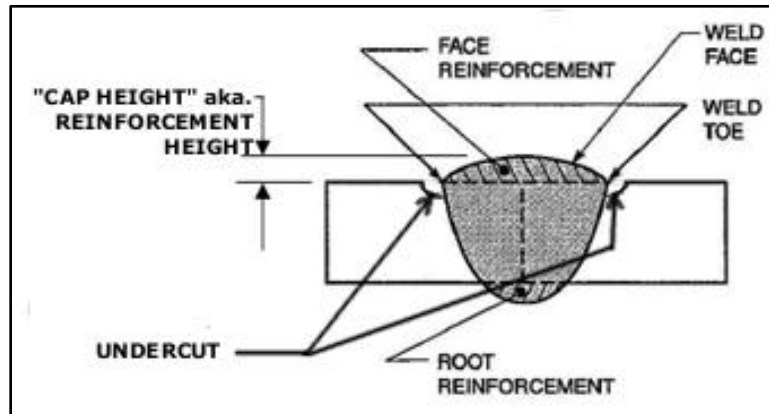


Figure 5: Cross section schematic of a weld showing cap height, referred to as reinforcement height.

3.1 Weld Creation

Based on the input received in the survey, several welding defects were identified as playing major roles in coating quality. Two welding defects were identified as major contributors in terms of their potential to adversely affect the integrity of subsequent coating operations: undercut and bead (cap) height. Using experimental practices and procedures developed at EWI, bead-on-plate welds were made with the desired defects each with different levels of severity. This allowed accelerated corrosion testing to determine the effect the increasing severity of welding defects on the resultant coating integrity. Only one welding process (GMAW) was evaluated, as welding defects are not dependent on the welding process (i.e., all arc welding defects were considered the same).

Bead-on-plate welds were made on grit blasted cold rolled A36 steel. The base plates were 3-in. wide by 9-in. long by 0.5-in. thick. Table 4 lists the welding equipment used to produce these welds. Photos of the geometry sample weld fixture are shown in Figure 6 and Figure 7. Upon completion of the welds, the test specimens were shipped to GTI for further analysis.

Table 4: Welding Equipment Used to Produce Geometry Samples

SIDE BEAM	Jetline with 9600 control
WELDING POWER SUPPLY	Miller Axxess450
WIRE FEEDER	Miller Axxess 40v
DATA ACQUISITION	ADM III with Wire, Voltage, Current sensors



Figure 6: Side View of Geometry Sample Welding Fixture



Figure 7: Front View of Geometry Sample Welding Fixture

The welding process constants used to produce the geometry samples are listed in Table 5.

Table 5: Welding Process Parameters used to Produce Geometry Samples

PROCESS	P-GMAW
PULSE PROGRAM SETTING	PULS, STL, 045, C10
FILLER/ELECTRODE	0.045-in. diameter, Hobart 30SP (ER70S-3)
WELD POSITION	Flat
SHIELDING GAS	Ar 85% / CO ₂ 15%
TRAVEL ANGLE	Zero
CONTACT TIP-TO-WORK	5/8-in.

Table 6 contains the desired weld attributes, the welding parameters used to produce them and the electrical characteristics of the welding process (as captured by the data acquisition system that was attached to the equipment).

Table 6: Targeted Conditions, Parameters and Actual Parameters from Data Acquisition Unit

Sample No.	TARGETED BEAD CONDITION			PARAMETERS				DATA ACQUISITION		
	Target Undercut	Target Bead Height	Target Spatter	Torch Travel Angle (deg)	WFS (in./min)	Trim	Travel Speed (in./min)	Wire Feed Speed (in./min)	Average Current (amps)	Average Voltage (volts)
1	0.000	0.100	None	drag 15	275	59	20.0	277	183	25.7
2	0.010	0.100	None	drag 15	275	60	20.0	278	182	26.0
3	0.020	0.100	None	drag 15	275	60	20.0	278	186	26.1
4	0.030	0.100	None	drag 15	275	60	20.0	278	184	26.0
5	0.000	0.075	None	push 35	250	62	25.0	247	177	24.8
6	0.000	0.125	None	drag 35	325	65	19.0	327	217	28.7
7	0.000	0.150	None	drag 35	450	40	22.0	452	265	25.5
8	0.000	0.100	Low	drag 15	275	70	20.5	276	195	28.3
9	0.000	0.100	High	drag 15	325	80	22.0	325	239	32.1
10	0.030	0.125	None	drag 35	325	65	19.0	329	220	28.8
11	0.030	0.075	None	push 35	250	62	25.0	252	173	25.8

3.2 *Simulated Girth Weld Testing*

GTI, following industry standards and recommended practices from the manufacture, prepared and coated the EWI simulated girth welds. This involved grit blasting the samples to a near white finish, confirmed with replica tape. The coating was then brushed on and allowed to cure.

Before evaluating the simulated girth weld created by EWI, GTI created sample welds to evaluate the various testing procedures under consideration.

3.2.1 GTI - Test Welds

The GTI samples consisted of a bare steel substrate and simulated girth welds with a nominal cap height of 0.125 inches corresponding to the larger cap height of the EWI simulated weld samples. The GTI samples were prepared using the same base steel and welding method the simulated girth welds from EWI. Figure 8 shows a sample where the bare steel was grit blasted to obtain a proper surface profile. The effectiveness of the grit blasting was verified by a replicate tape, which reproduces the surface profile so the peak to valley height can be measured. Figure 9 shows a GTI weld sample after being coated with Scotchkote 323, a commonly used brushable epoxy for pipeline protection.



Figure 8: Example of Properly Grit Blasted Steel Substrate



Figure 9: Coated GTI Sample

3.2.2 GTI Sample Tests and Results

Through testing, GTI determined that adhesion test (ASTM D 4541) was inadequate for evaluating the coating's effectiveness at the weld. The epoxy coating tested showed significant adhesion strength causing inaccurate measurements to be taken. The failures observed were a combination of cohesive failure within the coating and adhesive failure between the test apparatus and coating, see Figure 10. Additionally, there was no way to directly test the coating on the welded area as it is difficult to effectively attach the test mandrel in a consistent manner. The high adhesion strength of the epoxy also eliminates the tape test (ASTM D 3359) which could not approach the 3000 psi adhesion strength of the epoxy coating.



Figure 10: Left, the Al mandrel after testing. Right, the surface of the coating after testing.

The next series of tests examined how appropriate the drop test (ASTM G-14) would be to evaluate the geometric effects of the welds on the coating's effectiveness. This test centers on dropping a weighted tup, as shown in Figure 11, onto a coated surface and evaluating the results.

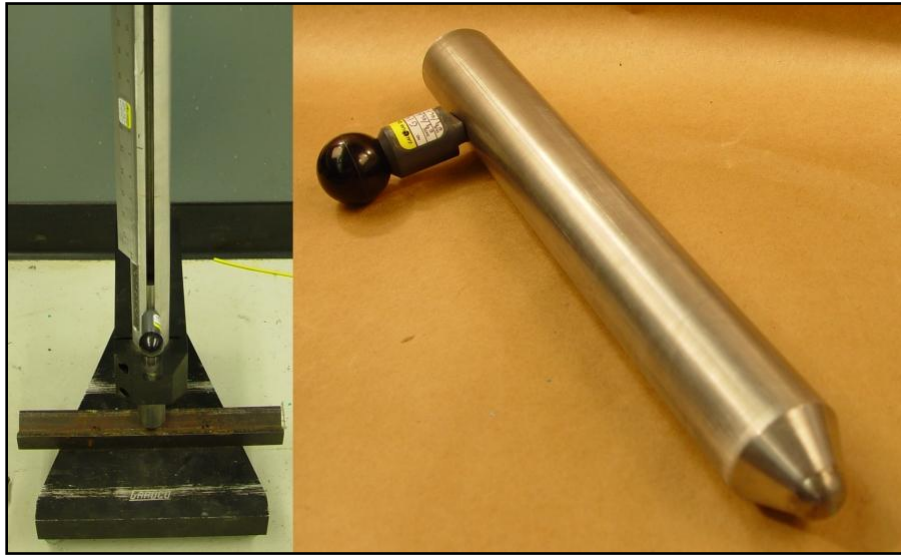


Figure 11: Left, impact tester. Right, the tup from impact tester, showing rounded tip.

Initial tests demonstrated that on flat stock, the coating was vigorously attached to the substrate. Tests performed on GTI-created weld samples showed failures occurred with much lower drop energies resulting in coating holidays as shown in Figure 12. This simulated possible failure conditions in the fields during the backfill operations. To then evaluate how the differences in geometry would enable corrosion, the samples were tested in a salt-fog chamber. The procedures used to evaluate the geometric effects on coating performance are contained in *Appendix C: Simulated Girth Weld Testing Procedures*.

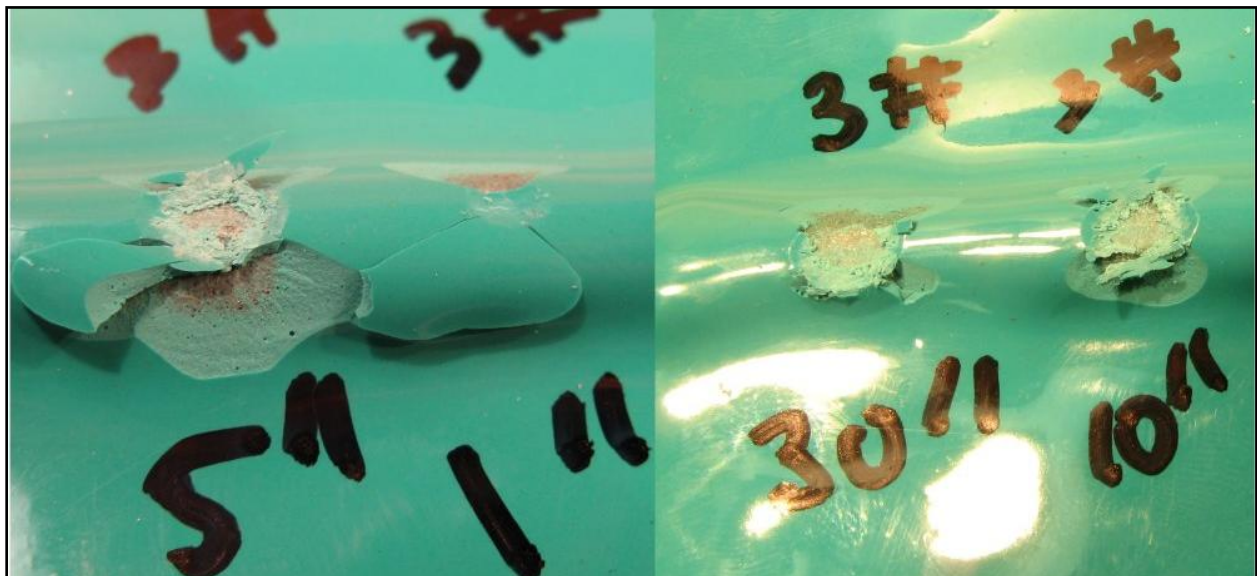


Figure 12: Drop tests on simulated GTI weld sample.

3.3 Test Procedure for Simulated Welds

A summary of what tests were applied to each sample is presented in Table 7, and short descriptions of the tests are contained in the next sections, a full procedure is located in *Appendix C: Simulated Girth Weld Testing Procedures*.

3.3.1 Cap Height Tests

The effects of cap height on the coating's performance will be established by performing impact testing followed by accelerated corrosion in a salt fog spray chamber. The basic steps included:

- Grit blasting and coating the EWI simulated girth weld samples,
- Cutting across the weld to expose the undercut, while not chipping the coating,
- Using the impact tester to strike the coated samples on the weld with a force which causes immediate failure in the sample with the lowest cap height,
- Verify through coating damage using a low voltage holiday detector,
- Accelerate deterioration of the coating in the salt fog chamber, and
- Compare the corrosion results to each other by quantifying the amount of corrosion, following ASTM D-610.

3.3.2 Undercut Tests

The effect of undercut on the performance of a coating was using the salt fog spray. The basic steps included:

- Grit blasting and coating of the EWI simulated girth weld samples,
- Cutting across the weld to expose the undercut, while not chipping the coating,
- Mask the cut edge to only expose the weld,
- Accelerate deterioration of the coating in the salt fog chamber,
- Compare the corrosion results to each other by quantifying the amount of corrosion, following ASTM D-610.

Table 7: Simulated Girth Weld Test Matrix

Sample ID	Replicates	Undercut (in.)	Bead height (in.)	Cap Height Test	Undercut Tests
1	2	0.000	0.100		2
2	2	0.010	0.100		2
3	2	0.020	0.100		2
4	2	0.030	0.100		2
5	2	0.000	0.075	2	
6	2	0.000	0.125	2	
7	2	0.000	0.150	2	
8	2	0.000	0.100	2	
9	2	0.000	0.100	2	
10	2	0.030	0.125	1	1
11	2	0.030	0.075	1	1

3.4 Cross Sections Analysis - Coating Thickness

The simulated girth welds were sectioned and coating thickness measurements were taken. Figure 13 shows a sample cross section image of a simulated weld that was used to measure the coating thickness on the weld and the substrate. The measurements were normalized, and showed a trend that increasing cap height reduces the coating thickness on the welded area, as shown in Figure 14. Table 8 contains the measurements of all the simulated girth welds. The cross-sectional images also show no strong effect from the undercut on the coating thickness. For complete set of images see *Appendix D: Simulated Girth Welds – Data*.

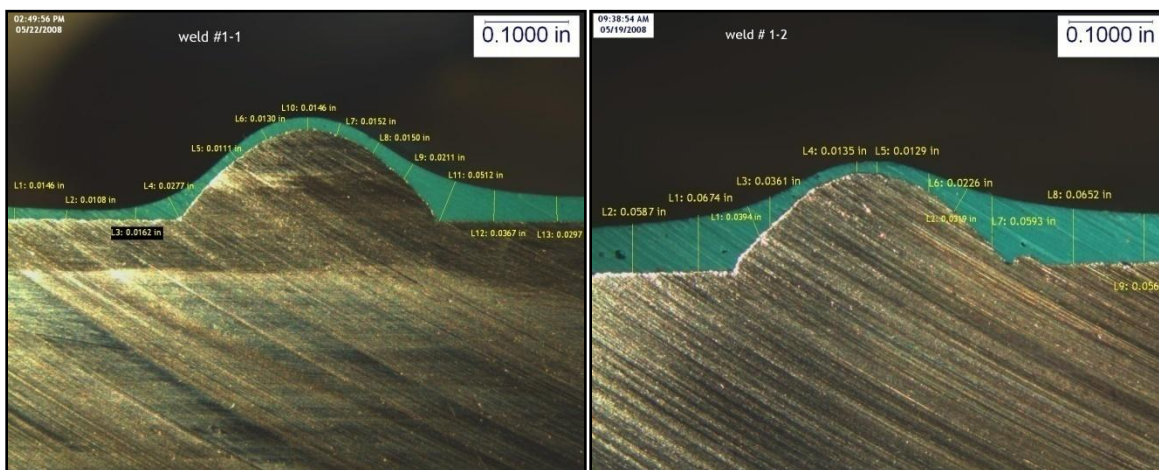


Figure 13: Sample Weld 1 Cross Section

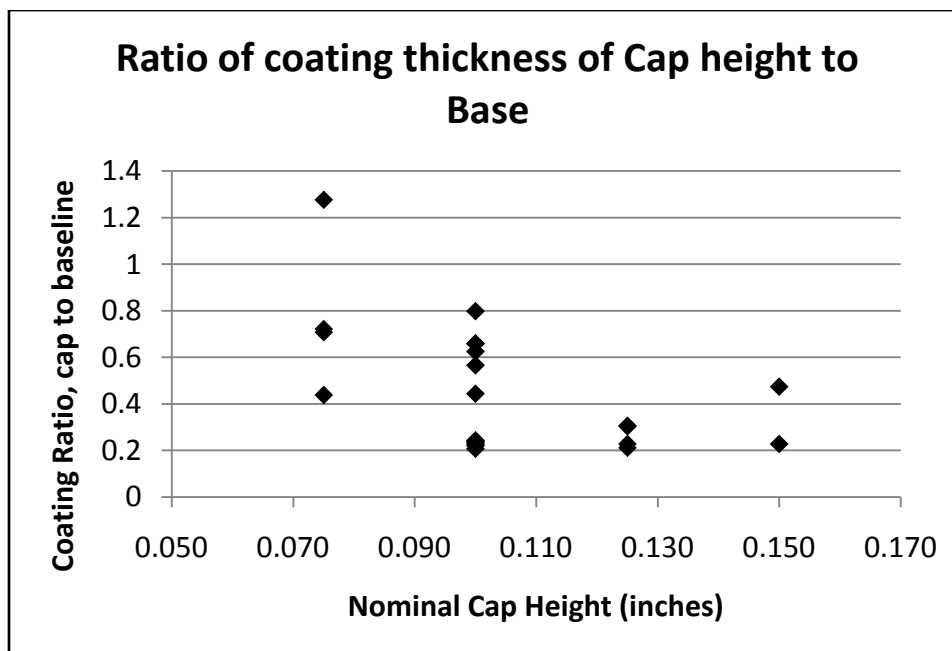


Figure 14: Graph of coating thickness ratio, cap height to baseline coating thickness.

Table 8: Measurements of Coating Thickness on Simulated Girth Welds*

Weld Number	Sub Number	Target Undercut (in.)	Target Bead (in.)	Target Splatter	Coating Thickness Ratio Cap/Base
1	1	0.000	0.100	None	0.66
	2				0.22
2	1	0.010	0.100	None	0.24
	2				0.24
3	1	0.020	0.100	None	0.66
	2				0.23
4	1	0.030	0.100	None	0.80
	2				0.23
5	1	0.000	0.075	None	0.71
	2				0.44
6	1	0.000	0.125	None	0.21
	2				0.23
7	1	0.000	0.150	None	0.47
	2				0.23
8	1	0.000	0.100	Low	0.57
	2				0.21
9	1	0.000	0.100	High	0.63
	2				0.44
10	1	0.030	0.125	None	0.31
	2				0.30
11	1	0.030	0.075	None	0.72
	2				1.28

*Note: Coating thickness ratio is the measurement of the thickness at the top of the weld cap divided by the average thickness of the coating far away from the weld.

3.5 Results of Simulated Girth Weld Testing

3.5.1 Undercut Test Results

A summary of the undercut results is presented in Table 9. The undercut area tended to pool the liquid coating and add to the coating thickness. This resulted in an increase in the coating's protection against corrosion. Figure 15 shows the corrosion of a sample when grit blasting was not performed. This is a worst case scenario representing the maximum possible damage under these conditions. Figure 16 shows sample 1-1 which was the poorest performing sample which still greatly outperformed the non-grit blasted sample. The remaining images of the samples are contained in *Appendix D: Simulated Girth Welds – Data*.

Table 9: Simulated Girth Welds – Undercut Tests*

Weld Number	Undercut (in.)	Cap Height (in.)	Coating Thickness at Cap (mils)	Rusted-off Coating at Cap (in.)	Rusted-off Coating Left Undercut (in.)	Rusted-off Coating Right Undercut (in.)
1-1	0.00	0.100	14.6	0.313	0.318	0.273
1-2	0.00	0.100	12.7	0.016	-	-
2-1	0.01	0.100	16.7	0.077	-	-
2-2	0.01	0.100	4.9	0.208	0.103	0.132
3-1	0.02	0.100	14.7	0.278	-	-
3-2	0.02	0.100	16.3	0.154	-	-
4-1	0.03	0.100	12.5	0.183	-	-
4-2	0.03	0.100	12.6	0.172	-	-
10-2	0.03	0.125	16.2	0.224	-	-
11-2	0.03	0.075	21.0	0.084	0.061	-

*Note: Measure of the amount of coating resulted under from the sample's edge



Figure 15: Bottom of simulated weld sample showing corrosion when grit blasting is not performed.



Figure 16: Simulated Girth Weld 1-1, after Picking

3.5.2 Cap Height Test Results

There were no clear methods to measure the damage from the initial impact for the accelerated corrosion testing. Photos were taken after the impacts were performed but to prevent additional damage no coating was forcibly removed. This made determining the amount of coating damaged by the impacts difficult to evaluate, as seen in Figure 17. The coating's surface damage does not correlate directly to any through-coating damage. The actual area of the holiday from the impact could not be determined. Measurements of the area of coating damaged before and after the accelerated corrosion testing are presented in Table 10. A negative number indicates the original coating damage was overestimated because the impact caused larger coating surface damage area than holiday area. This caused the area post accelerated corrosion testing to be lower than that of the initial impact area. Figure 18 through Figure 20 present an example of the before and after salt fog testing using sample 9-1. Looking at these images the impact clearly chipped significant amounts of the coating off the weld. The overall observed corrosion increased with the initial exposed steel surface area. The salt fog exposure caused the exposed steel to rust and damage the coating around the holiday. The area of rusting was evaluated by picking at the sample with a dull knife following ASTM D-610, and photographing the results.

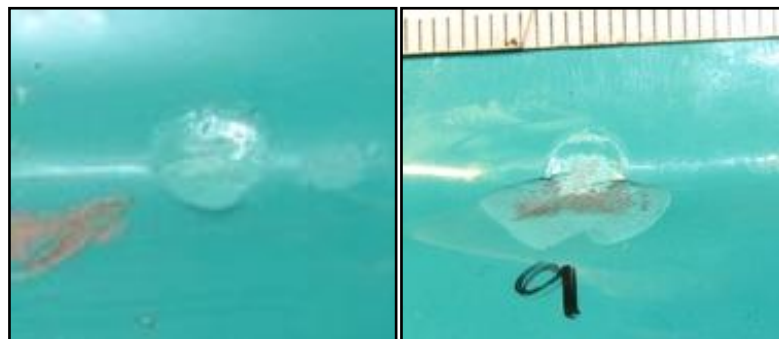


Figure 17: Surface damage after impacting the simulated girth weld samples. Left, surface damage with an unknown holiday. Right, surface damage and a known holiday.

Table 10: Area of Coating Removed Before and After Salt-fog Testing.

Weld Sample	Cap Height (in.)	Coating Thickness (mils)	Area Pre-acc. Testing (sq. in.)		Area Post-acc. Testing (sq. in.)		Area Change (%)	
			A	B	A	B	A	B
5-1	0.075	18.3	0.045	0.047	0.066	0.057	47	21
5-2	0.075	25.4	0.025	0.037	0.055	0.004	120	-89
6-1	0.125	13.5	0.045	0.056	0.056	0.046	24	-18
6-2	0.125	20.5	0.028	0.033	0.000	0.053	-100	61
7-1	0.150	17.0	0.031	0.040	0.087	0.061	181	53
7-2	0.150	12.4	0.040	0.062	0.111	0.138	178	123
8-1	0.100	14.2	0.027	0.037	0.082	0.068	204	84
8-2	0.100	16.2	0.030	0.029	0.079	0.050	163	72
9-1	0.100	16.2	0.075	0.063	0.104	0.050	39	-21
9-2	0.100	5.4	0.027	0.029	0.066	0.054	144	86
10-1	0.125	14.0	0.058	0.046	0.136	0.102	134	122
11-1	0.075	16.2	0.018	0.021	0.003	0.006	-83	-71

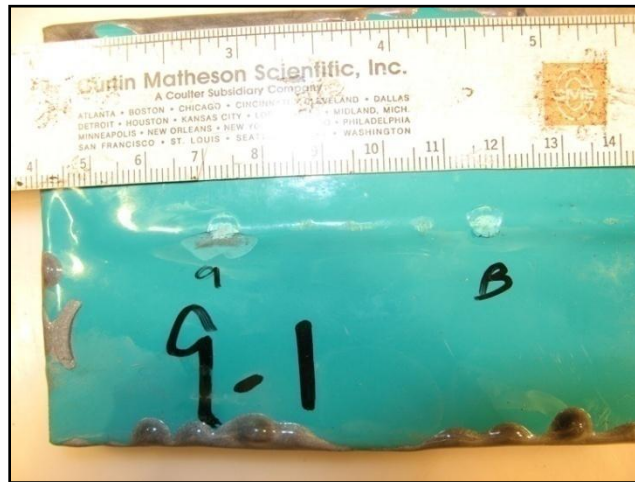


Figure 18: Sample 9-1 after impacts and before accelerated corrosion testing.



Figure 19: Simulate girth weld 9-1, after salt fog exposure.



Figure 20: Simulate girth weld 9-1, after picking.

3.6 Conclusions from Simulated Girth Welds

These welds were made to investigate the effects of different geometry features, specifically cap height and undercut. A liquid applied coating was utilized for this testing as this is a common method of coating application.

3.6.1 Undercut (0.000 to 0.030 inches)

The increasing undercut had little effect on the liquid brushable two part epoxy coating. The void of the undercut was filled with the liquid and actually added to the thickness of the coating as measured from the undercut. This implies the liquid coating wet the undercut surface well. The coating in the undercut regions could not be removed in nearly all of the samples meaning the corrosion did not advance along the undercut. Within these conditions increasing undercut depth did not lead to greater susceptibility to corrosion. Undercut showed no negative effects on the liquid applied protective coating. However, these

results may not transfer the FBE coatings as they are applied fundamentally different and may not "fill in" the undercut region as effectively as the liquid coating.

3.6.2 Cap Height (0.075 to 0.150 inches)

Increasing cap height led to increased thinning of the liquid brushable two part epoxy. The combination of the thinner coating and increased angle from a higher cap height made these welds more susceptible to damage. This was shown with increased initial damage from the same impact energies on higher cap height samples than the lower cap height samples. However, the rusting did not advance to a greater degree due to the increased cap height; instead it advanced based on the area of initial damage. Within these conditions increasing cap height led to a greater suitability to damage but did not increase corrosion rates.

3.7 *Summary of Geometric Effects Test Results*

The simulated girth welds investigated geometric effects of the weld on a liquid applied coating performance. Undercuts up to 0.03 inches were found to have no significant effect on a coating's resistance to corrosion. The undercut tended to add to the coating thickness and therefore potentially increased its resistance to corrosion. Increasing cap height of a weld was found to thin the coating making it more susceptible to chipping. The salt fog environmental chamber did not preferentially accelerate the corrosion on the increasing cap height samples. The amount of corrosion growth was more dependent on the initial impact size which was dependent on the cap height. With proper coating preparation and application procedures, especially surface profiling, the weld geometries investigated in this phase of the project had no strong negative effects on liquid two part epoxy coating performance. Since FBE coatings are applied in a different manner, these results cannot be extended from liquid to FBE coatings. If the FBE provides the same wetting of the undercut and similar coating thickness on the cap height one would expect similar results.

Hydrogen Off-gassing Test - In-Field Welds

The primary goal of the in-field welds is to evaluate the effects of hydrogen off-gassing on two common coating products. Concerns have been raised that various welding mediums leave diffuse hydrogen in the welded area that diffuses out of the steel, causing damage to the protective coating. The minimum time between welding operations and coating operations to prevent off-gassing damage has not been determined and incorporated into industry standards. Identifying a hold time before beginning coating operations will provide operators and regulators a set of guidelines/regulation for hold time before coating operations can commence. The in-field testing allowed GTI and EWI to directly observe welding and coatings operations communication. This helped to identify and recommend improvements for a communication protocol.

4.1 Weld Matrix

The test matrix was designed to test the effects of hydrogen off-gassing on the performance of protective coatings on pipeline girth welds. The off-gassing will be controlled by varying the hold time between welding and coating operations, creating an in-field level of hydrogen. Table 11 shows the various welds performed, conditioning/hold time, and coating applied. The gas metal arc welding (GMAW) process uses a relatively low hydrogen producing electrode. Shielded metal arc welding (SMAW) or stick welding can utilize electrode that are medium to high hydrogen producing. The 7010 electrode is a commonly used pipeline welding medium and has high hydrogen production. The 7018 is an electrode for stick welding that has a medium level of hydrogen production. After each weld is completed, it was conditioned. A conditioning time of 2 hours or 5 hours means the girth weld was held for that amount of time before the coating operations begin. The preheat specimens were heated with induction coils or torches before coating application to accelerate hydrogen off-gassing. In Table 11 Coating refers to which of the two coatings were applied, either a fusion bonded epoxy (FBE) or a two-part Epoxy. These two coating materials were chosen because of their good performance in the *GTI Field Applied Coating* study and because more than 60% of survey respondents use these classes of coatings.

Table 11: In-field Weld Matrix

Weld	Process	Size	Conditioning	Coating
Girth Weld	GMAW	24 inch	2 hr	FBE
Girth Weld	GMAW	24 inch	5 hr	FBE
Girth Weld	GMAW	24 inch	FBE Preheat	FBE
Girth Weld	GMAW	24 inch	2 hr	Epoxy
Girth Weld	GMAW	24 inch	5 hr	Epoxy
Girth Weld	GMAW	24 inch	Torch Heat	Epoxy
Girth Weld	7010	6 inch	2 hr	FBE
Girth Weld	7010	6 inch	5 hr	FBE
Girth Weld	7010	6 inch	FBE Preheat	FBE
Girth Weld	7010	6 inch	2 hr	Epoxy
Girth Weld	7010	6 inch	5 hr	Epoxy
Girth Weld	7010	6 inch	Torch Heat	Epoxy
Girth Weld	7018	6 inch	2 Hr	FBE

4.2 Weld Creation and Coating

The full size weld specimens were intended to simulate the welding conditions experienced in the field. Girth welds were deposited with SMAW (using both cellulosic and low-hydrogen type electrodes) and with GMAW (which features a bare solid wire that is considered a low-hydrogen welding process).

Prior to depositing the girth welds, each pipe joint was preheated to 150°F. This temperature was chosen because it is the preferred practice to decrease the likelihood of forming hydrogen cracks. The interpass temperature for the GMAW welds was 350°F and the interpass temperature for the SMAW welds was 180°F. All welds were cleaned using a wire wheel to remove any slag and loose spatter that may have adhered to the weld region.

After welding, all the welds except for one GMAW weld, and one SMAW weld made with cellulosic electrodes, were cooled to room temperature by forced air using a floor fan. The accelerated cooling was used to simulate a worst case scenario to trap as much hydrogen in the weld as possible. 20- to 40-ft. long pipe (and longer) tend to pull heat away from the weld region at a faster rate than the shorter 1- to 2-ft. sections used for this study. Short length pipes tend to heat up faster and remain at an elevated temperature. Forced air cooling increased the rate at which heat was removed from the smaller samples. After cooling, the welds were transported to Commercial Coating Services Inc (CCSI) for coating.

The two welds that were not allowed to cool down were subjected to a post weld bake-out. The bake-out consisted of heating the weld to 250-350°F for ten minutes using a propane torch (Figure 21). The post weld bake-out was intended to accelerate the diffusion of hydrogen from the weld in an effort to increase the likelihood of a successful coating. Previous research has shown that bake-out time in this temperature range has successfully reduced hydrogen cracking susceptibility. The propane torch was used for heating since it is a common heating method used by pipeline welders.



Figure 21: Post Weld Bake-Out with Propane Torch

Two of the welds that were cooled to room temperature were also exposed to a hydrogen bake-out step; however, this bake-out cycle was performed with an induction coil. Since an induction coil is typically used to apply FBE for pipeline field coatings, this alternative bake-out step could be carried out

by the coating personnel instead of the welding personnel. The complete matrix of the welds completed at CRC EVANS is listed in Table 12.

Table 12: Full-Scale Weld Matrix

Joint	Girth Weld				
Process	GMAW		E7010		E7018
Coating	FBE	Liquid	FBE	Liquid	Liquid
2 Hour Hold	X	X	X	X	X
5 Hour Hold	X	X	X	X	
Induction Heating	X		X		
Torch Heating		X		X	

4.2.1 GMAW Girth Welds

The GMAW welds were deposited in the 5G position using one of CRC-Evans standard welding procedures. In the 5G position the pipe is stationary and the welder performs the weld moving around the pipe. The root pass was deposited using an internal welding bug with six GMAW welding torches (Figure 22 and Figure 23). The welds were deposited from the outside diameter (OD) with a combination of single torch and dual torch welds in the double down welding progression (Figure 24 thru Figure 27).



Figure 22: CRC-Evans Internal Multi-Torch Welding Bug for Root Pass Deposition

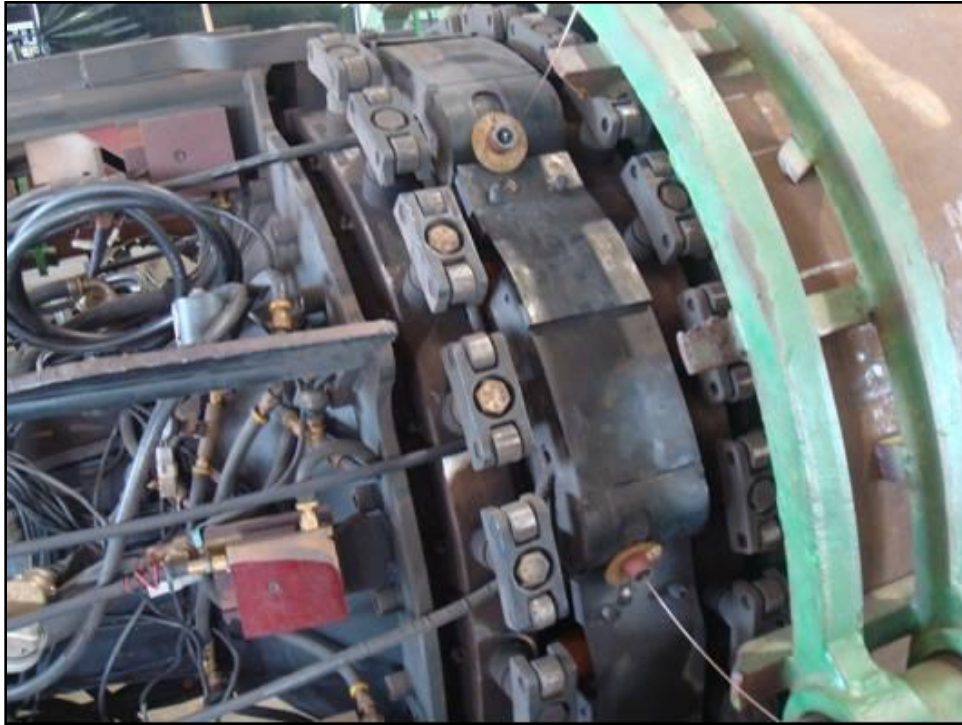


Figure 23: Close-up of Internal Welding Bug Showing Two of the Six Torches

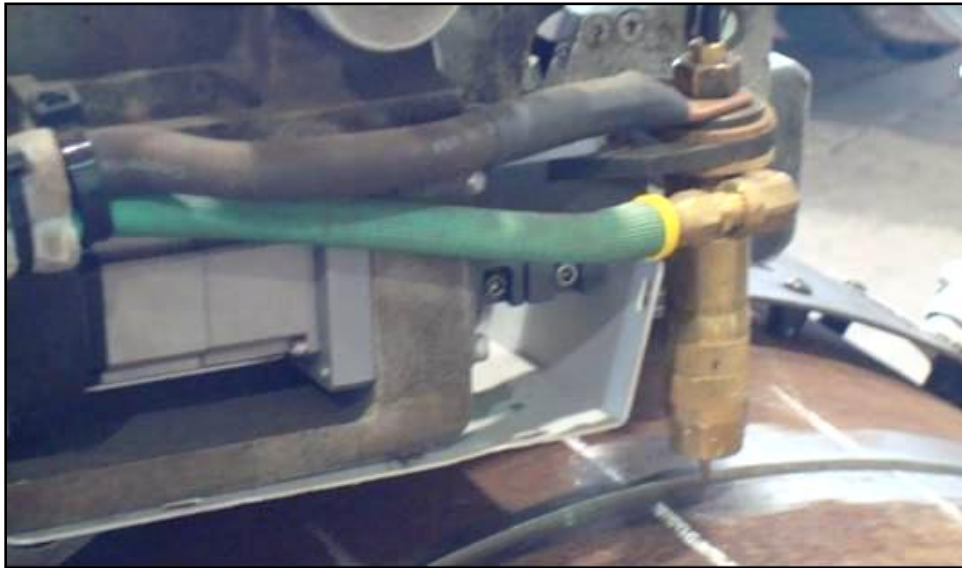


Figure 24: CRC-Evans Single Torch Welding Bug



Figure 25: CRC-Evans Dual Torch Welding Bug



Figure 26: CRC-Evans Dual Torch Welding Bug Depositing Fill Passes



Figure 27: Weld Joint after a Dual Torch Fill Pass



Figure 28: Representative Completed GMAW Weld

The welding procedure used by CRC-Evans to deposit the GMAW girth welds is in *Appendix E: In-Field Weld – Data*. The joint used for the GMAW girth welds is illustrated in Figure 29.

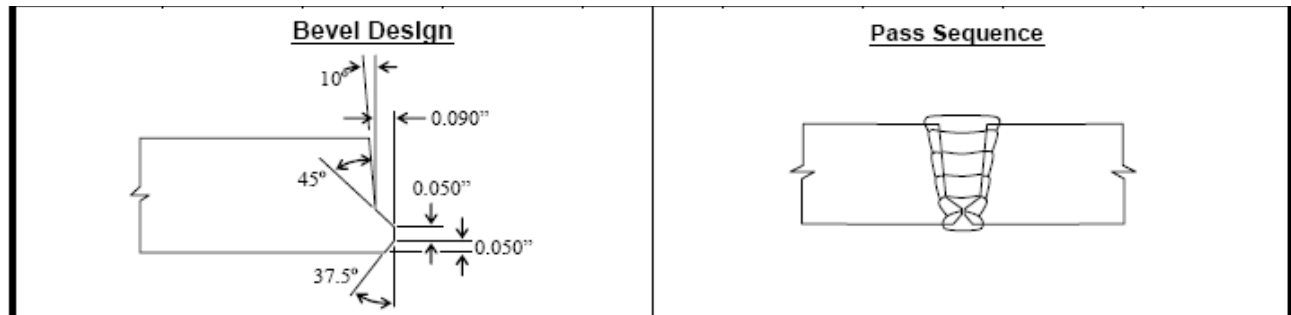


Figure 29: Joint Design and Bead Sequence for the GMAW Girth Welds

4.2.2 SMAW Girth Welds

The SMAW welds were also deposited in the 5G welding position (Figure 30). The typical welding parameters used to deposit the SMAW welds using E7010 electrodes are provided in Table 13. The weld joint used for the SMAW girth welds were 45° included angle bevels with a 1/16-in. joint gap. The E7010 SMAW welds were deposited with a downhill welding progression. All the weld layers were deposited as a single pass layer except for the final fill passes which were deposited as a two pass layer. The cap pass was deposited as a single layer weave. The typical bead appearance for the E7010 SMAW girth welds is shown in Figure 31 and Figure 32.



Figure 30: Girth Welding with the SMAW Process

Table 13: Typical Per Pass Welding Parameters for the 7010 SMAW Girth Welds

Pass	Electrode Diameter (inch)	Current (amps)	Voltage (volts)	Travel Speed (in./min)
Root	1/8	75 - 85	24 - 28	3 - 5
Hot Pass	1/8	105 - 115	26 - 30	7 - 9
Fill	5/32	140 - 150	24 - 28	7 - 9
Fill	1/8	110 - 120	26 - 30	7 - 9
Cap Pass	5/32	130 - 140	25 - 29	5 - 7



Figure 31: Typical Root Pass Appearance of a SMAW Girth Weld



Figure 32: Typical Completed Weld Appearance for SMAW Girth Weld

The one E7018/E6010 SMAW girth weld was also deposited in the 5G welding position. The root pass was deposited in a downhill progression, while the fill and cap passes were deposited in the uphill welding progression using the E7018 electrodes. The welding parameters for the root pass were the same parameters that were listed in Table 13. The typical parameters that were used with the 7018 electrodes are shown in Table 14.

Table 14: Typical Per Pass Welding Parameters for the 7018 SMAW Girth Welds

Pass	Electrode Diameter (inch)	Current (amps)	Voltage (volts)	Travel Speed (in./min)
Hot Pass	1/8	135 - 145	20 - 24	5 - 7
Fill	1/8	135 - 145	20 - 24	6 - 8
Cap Pass	1/8	135 - 145	20 - 24	6 - 8

4.2.3 Weld Coating

The finished welds were labeled with the time of completion and then transported to CCSI for coating application. The appropriate conditioning was applied before any coating operations took place. After the conditioning the welded area surface was prepared and coated. The steps to perform the coating once the welded pipe was received were:

- Torch heat at welding facility (if called for),
- Wait predetermined conditioning time,
- Sand blast the pipe section (Figure 33 and Figure 34),

- Perform salt test on welded pipe section,
- Perform anchor profile measurement of blasted surface,
- FBE preheat (if called for), inductively heating the pipe and then letting it condition a further 10 minutes (Figure 35),
- Apply coating following manufactures suggested application, record environmental conditions during application, and
- Measure wet coating thickness for two-part epoxy and dry thickness for FBE.

Photographs of the surface preparation and coating application:



Figure 33: Sandblasting of Pipe Section



Figure 34: Small Girth Weld (6 inch pipe) that has Been Sand Blasted



Figure 35: Inducer Coil on Large Weld to Heat Pipe Before FBE Application



Figure 36: FBE Powder Application on a 24 inch Welded Pipe Section

Figure 37 through Figure 40 show the completed coated welds of the various pipe diameters and coating materials.



Figure 37: Cured FBE Coating on 24 inch Welded Pipe Section



Figure 38: Cured FBE Coating on 6 inch Welded Pipe Section



Figure 39: Cured 2-part Epoxy on 24 inch Welded Pipe Section

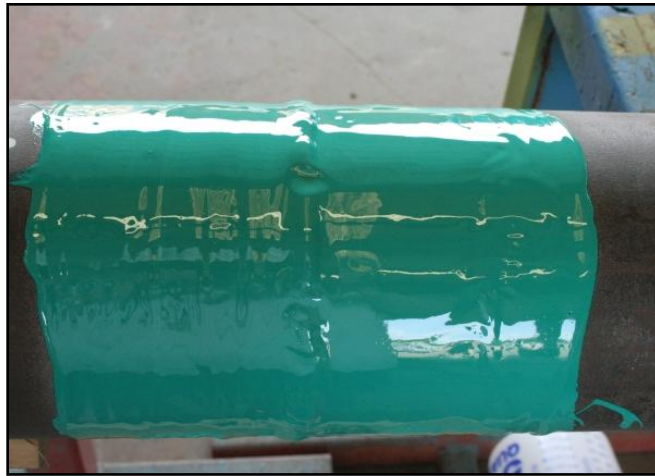


Figure 40: Cured 2-part Epoxy on 6 inch Welded Pipe Section

The measurements taken of the salt level, and during coating application are located in *Appendix E: In-Field Weld – Data*. These values were recorded to provide additional information on the welded specimens, to help prevent ambiguous results by knowing as many of the variables as possible.

4.3 Coating Testing

Hydrogen off-gassing would weaken the adhesion of the protective coating and cause pores to develop within the coating.⁵ To assess any drop in adhesion, direct adhesion strength measurements were attempted. The pull-off adhesion tests were insufficient to create a failure at the coating pipe interface, see Figure 41. This indicated there was not a dramatic reduction in adhesion strength from hydrogen off-gassing, or that a large porous layer created. In lieu of other testing methods it was determined that cross-sectional images would help establish if hydrogen bubbles were trapped within the coating, and that cathodic disbondment tests would evaluate the coatings' adhesion.

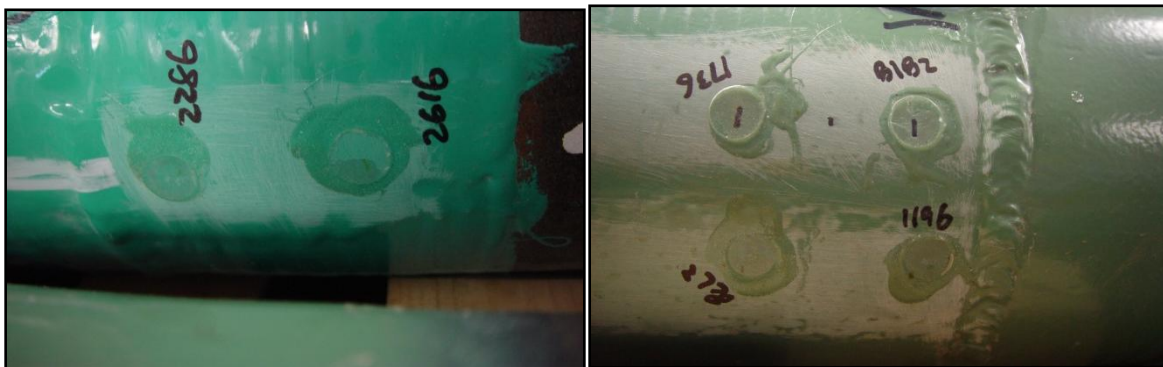


Figure 41: Pull off adhesion testing of two coatings showing a mixed failure mode.

4.3.1 Cross-section Analysis

Sections of the 24" diameter in-field welds were removed and polished in profile to image the coating's edge and interface with the steel pipe. Figure 42 shows the presence of small voids or bubbles in the coatings applied in the field. These types of voids were also observed in the simulated girth weld samples. It has been previously argued that hydrogen off-gassing results in an increase of voids within a coating near a weld. The voids could then weaken the coating's resistance to corrosion. Examining the

cross sections of the large 24 inch diameter welds, no increase in void density was found near the weld bead. This is shown in Figure 43 for the 2 hour hold time sample with a 2-part epoxy coating. The remaining images are located in *Appendix E: In-Field Weld – Data*. The void density appears to not be related to the proximity of the weld bead or hold time. This indicates that there is not significant enough hydrogen off-gassing from the automated GMAW welding process used to create these samples to create a noticeable number of voids.

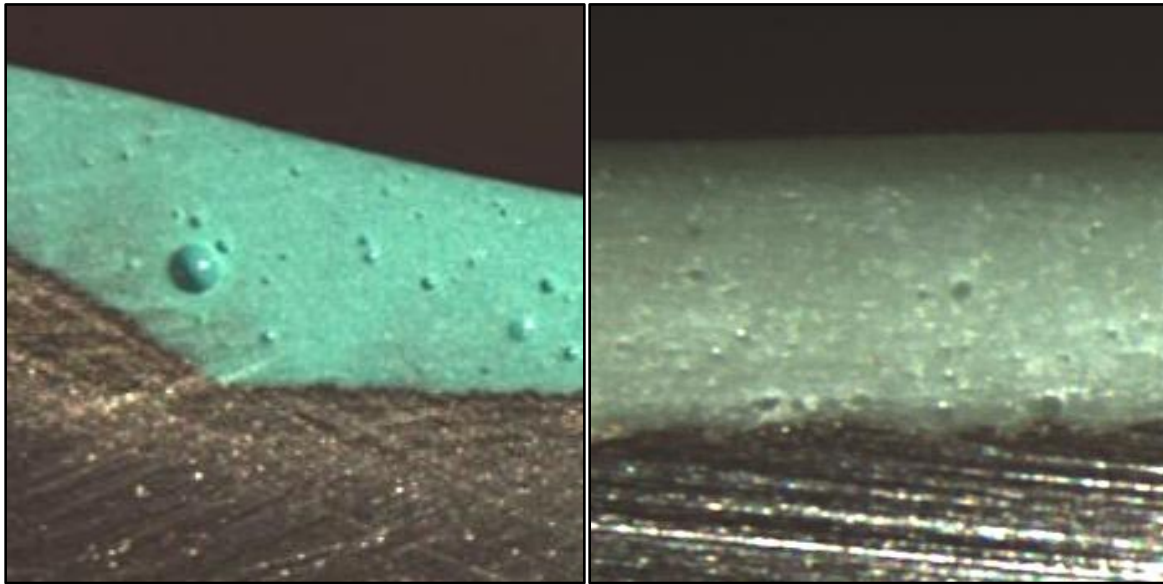


Figure 42: Left, voids in a 2-part epoxy coating. Right, voids in a FBE coating.

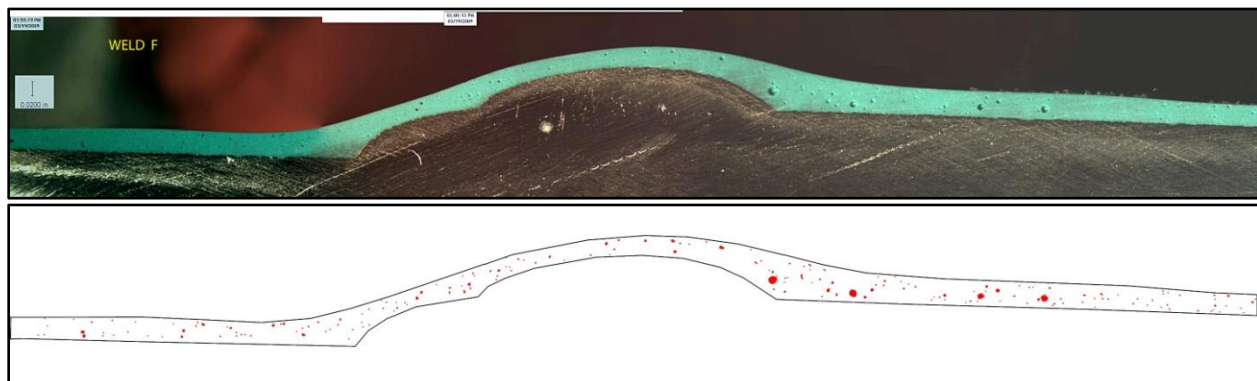


Figure 43: Top, cross-section image of the 2-part epoxy coating applied after a hold time of 2hrs. Bottom, is an outline of the coating and red dots indicating the presence of a void.

4.3.2 Cathodic Disbondment Testing

Cathodic disbondment (ASTM G 95) tests were carried out to evaluate the coating's adhesion strength. The test is carried out by first creating a holiday through the coating and then attaching a cell, filled with a salt water solution into which a platinum electrode is inserted. A voltage is applied across the electrode and the pipe, causing hydrogen gas to be generated at the surface of the steel in the holiday.

The hydrogen then disbonds the coating at a rate that is dependent on the coating's adhesion. After 90 days the amount of coating that has been disbonded around the holiday is evaluated in comparison to a control holiday in which no purposeful disbondment has occurred. See Figure 44 and Figure 45 for pictures of the cathodic disbondment test setup. The drilled holiday was placed near but not on the weld to provide a consistent surface and a larger chance of a hydrogen off-gassing effect, since Hydrogen off-gassing would preferentially affect the coating closer to the weld.



Figure 44: In-field welded test sections with ongoing cathodic disbondment testing.

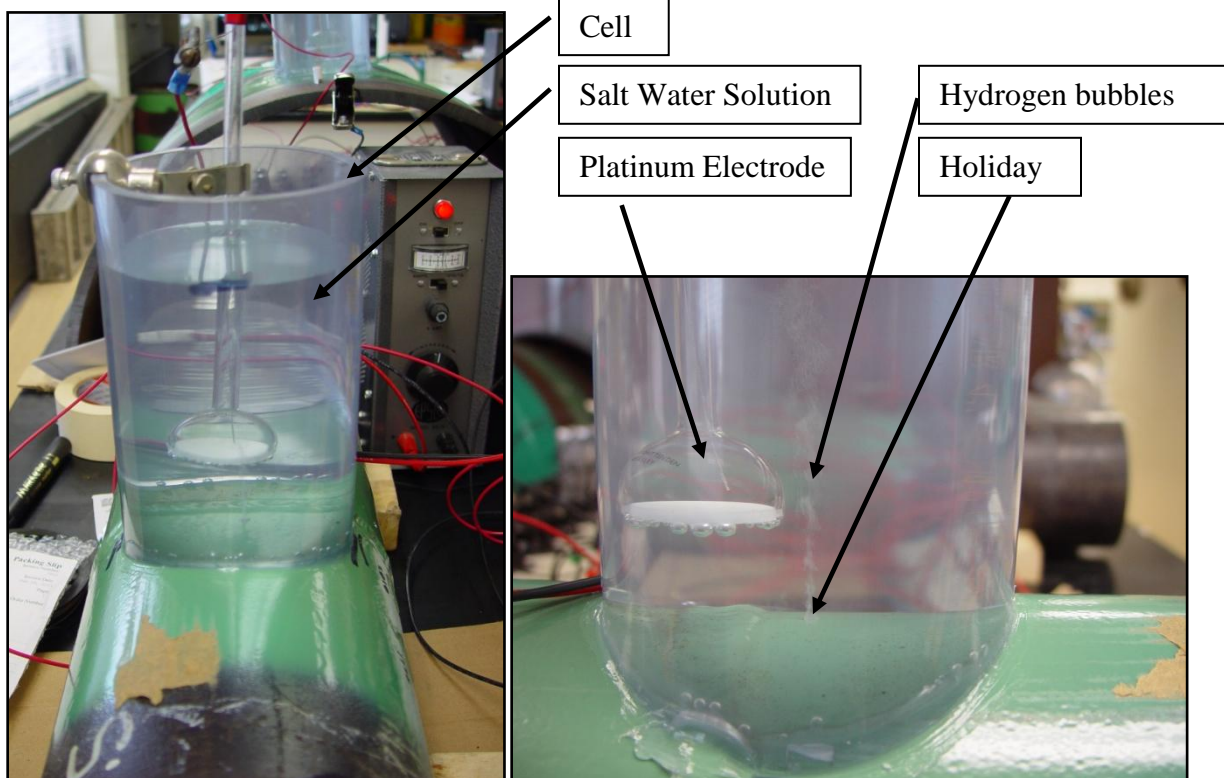


Figure 45: A welded pipe section with an attached cell to perform cathodic disbondment tests.

4.4 Cathodic Disbondment Results

To establish base line results, data from GTI's previously performed *Field Applied Coating* project was reviewed. Previous cathodic disbondment tests were performed on the same coatings tested in this project, see Figure 46 and Figure 47. This data represents a baseline of performance on a well coated surface and carefully applied coatings.



Figure 46: 2-Part Epoxy cathodic disbondment result from GTI's *Field Applied Coating* project.

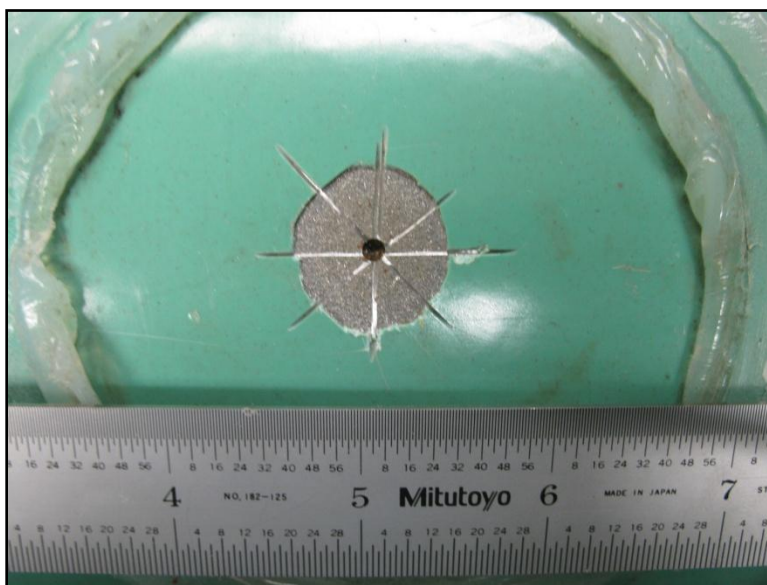


Figure 47: FBE cathodic disbondment result from GTI's *Field Applied Coating* project.

The reference cathodic disbondment tests show that some coating disbondment is expected with these tests, as seen in Table 15. The cathodic disbondment tests are not absolute measurements of a coating's adhesion strength but provide comparative information on the adhesion strength.

Table 15: Cathodic disbondment results from GTI's *Field Applied Coating* project for baseline comparisons.

Coating	Coating Thickness (mils)	Average Disbondment radius (in.)
2-part Epoxy	15.0	15/32
FBE	25.4	13/32

The disbondment tests on the in-field welds were completed and analyzed. Two disbondment measurements were recorded: 1 – the amount of disbondment in the directions of the weld and 2 – the amount of disbondment away from the weld. If the hydrogen off-gassing has a substantial effect on the welded area it is expected that the disbondment will be consistently greater towards the weld in the shorter hold time samples. Table 16 and Table 17 show a summary of the results from the analysis.

Table 16: 6 inch diameter in-field welds, summary of cathodic disbondment testing [High Hydrogen – SMAW with 7010 electrode]

Sample #	Description	Coating Thickness Average(mils)	CD toward weld (in.)	CD away from weld (in.)
1	FBE – 2 Hour Hold	28.8	2/32	2/32
2	FBE – 5 Hour Hold	14.7	12/32	12/32
3	FBE – Preheat	20.7	10/32	12/32
4	2-Part – 2 Hour Hold	27.2	8/32	8/32
5	2-Part – 5 Hour Hold	27.6	4/32	4/32
6	2-Part – Preheat	23.3	6/32	16/32
7	Electrode 7018: FBE – 2 Hour Hold [Med. Hydrogen]	11.4	19/32	16/32

Table 17: 24 inch diameter in-field welds, summary of cathodic disbondment testing [Low Hydrogen – GMAW process]

Sample #	Description	Coating Thickness Average (mils)	CD toward weld (in.)	CD away from weld (in.)
21	2-Part – Preheat	29.1	14/32	2/32 *extra thick coating in this direction
22	FBE – 5 Hour Hold	17.5	12/32	10/32
23	2-Part – 5 Hour Hold	11.8	11/32	18/32
24	FBE – Preheat	34.4	2/32	2/32
25	2-Part – 2 Hour Hold	31.8	2/32	2/32
26	FBE – 2 Hour Hold	35.6	2/32	2/32

Appendix E: In-Field Weld – Data contains the pictures of the cathodic disbondment results. For each sample there is a picture of the disbondment area prior to analysis, a picture of the reference area, and a picture of the disbondment area after picking the coating following the standard.

4.5 In-field Welds Analysis

These welds were created and coated with industry partners utilizing common coating materials that performed well in previous GTI testing. Two different methods of weld creation were used to have a higher (on 6 inch pipe) or lower (on 24 inch pipe) likelihood of hydrogen off-gassing. All samples were created while trying to minimize any differences except in the specified variables. Proper weld and surface preparations were made and coatings were applied following all manufacturing specifications.

4.5.1 FBE on 24 Inch Pipe

Three samples of FBE on 24 inch diameter pipe were created and subjected to cathodic disbondment testing. Analysis of the samples shows no correlation of coating performance to the hold time after weld creation. The 5 hour hold sample had the largest disbondment area, but should also have the least effects from hydrogen off-gassing. It seems that the coating thickness was a dominate factor with a thicker coating performing better. Within these conditions a 2 hour hold time was sufficient to prevent any damage from Hydrogen off-gassing to a properly applied FBE coating.

4.5.2 FBE on 6 Inch Pipe

These samples were created with a hydrogen rich welding medium to produce a "worst case" scenario on the 6 inch diameter pipe coated with FBE. Analysis of the samples shows no correlation between coating performance and hold time after weld creation. The least disbondment area was found on the 2 hour hold time sample which would have had the most negative effects from any hydrogen off-gassing. However, it seems that the coating thickness was a dominant factor with a thicker coating performing better. Within these conditions a 2 hour hold time was sufficient to prevent any damage from Hydrogen off-gassing to a properly applied FBE coating.

4.5.3 2-Part Epoxy on 24 Inch Pipe

Three samples of 2-part epoxy applied to 24 inch diameter pipe girth welds were created and subjected to cathodic disbondment testing. Analysis of the samples shows no correlation of coating performance to the hold time between welding and coating. The least disbondment area was found on the 2 hour hold time sample which should have the most negative effect from hydrogen off-gassing. However, it seems that the coating thickness was a dominant factor with a thicker coating performing better. Within these conditions a 2 hour hold time was sufficient to prevent any damage from Hydrogen off-gassing to a properly applied 2-part epoxy coating.

4.5.4 2-Part Epoxy on 6 Inch Pipe

These samples were created with a hydrogen rich welding medium to produce a "worst case" scenario on the 6 inch diameter pipe coated with 2 part epoxy. Analysis of the samples shows no clear correlation of coating performance to the hold time between welding and coating operations. Local variations of coating thickness account for the variance in the disbondment area. Within these conditions

a 2 hour hold time was sufficient to prevent any damage from Hydrogen off-gassing to a properly applied 2-part epoxy coating.

4.6 *Summary of In-Field Welds*

The in-field welds were created to test the effects of hydrogen off-gassing on coating performance. Two different welding mediums were used, one with a high hydrogen content and one with a low hydrogen content. These different welds were then held for 2 or 5 hours to vary the amount of time allowed for Hydrogen off gassing and then coated in either FBE or a liquid 2 part epoxy. The cross-sections of the 24" diameter pipes showed no increase of voids above the welded area indicating there was little off-gassing in these samples after the two hour mark. All other variables were held as constant as possible. Cathodic disbondment testing, ASTM G 95, was performed to evaluate the coating's adhesion properties, and no detectable differences were found that could be attributed to the hydrogen off-gassing from the weld. The disbonded area was symmetrical with no preference toward the welded area that would have had more hydrogen off-gassing effects. The variance found in performance did not correlate with hold time and were within the range of tests previously performed by GTI. This indicates when using these welding mediums and properly preparing the pipe surface, a hold time of two hours is sufficient to minimize any hydrogen off-gassing effects.

Conclusions

GTI and EWI created both laboratory and in-field girth weld samples to evaluate the effects of weld geometry and hydrogen off-gassing on protective coating performance. Simulated welds were used to tightly control geometric differences and in-field welds were created to mimic welding conditions and hydrogen off-gassing. These welds were then coated and tested with accelerated corrosion techniques to evaluate the effectiveness of the coatings.

The simulated girth welds investigated geometric effects of the weld on a liquid applied coating performance. Undercuts of up to 0.03 inches were found to have no significant effect on a coatings resistance to corrosion. The undercut tended to add to the coating thickness and therefore increased its resistance to corrosion. Increasing cap height of a weld was found to thin the coating making it more susceptible to chipping. The salt fog environmental chamber did not preferentially accelerate the corrosion of the samples with increasing cap height. The amount of corrosion growth was more dependent on the initial impact size which was dependent on the cap height. When applying proper coating procedures, especially surface profiling, the weld geometries investigated had no strong negative effects on liquid two-part epoxy coating performance. Since FBE coatings are applied in a different manner, these results cannot be extended from liquid to FBE coatings, but if the FBE provides the same wetting of the undercut and similar coating thickness on the cap height one would expect similar results.

The in-field welds were created to test the effects of hydrogen off-gassing on coating performance. Two different welding mediums were used, one with a high hydrogen content and one with a low hydrogen content. These different welds were then held for 2 or 5 hours to vary the amount of time allowed for hydrogen off-gassing and then coated in either FBE or a liquid two-part epoxy. Relative to remote locations the cross-sections of the 24 inch diameter pipes showed no increase void density near the welded area indicating there was little off-gassing in these samples after the two hour mark. All other variables were held as constant as possible. Cathodic disbondment testing, ASTM G 95, was performed to evaluate the coating's adhesion properties, and no detectable differences were found that could be attributed to the hydrogen off-gassing from the weld. The disbonded area was symmetrical with no preference toward the welded area (that would have more hydrogen off-gassing effects). The variance found in performance did not correlate with hold time, and were within the range of tests previously performed by GTI. This indicates when using these welding mediums, and properly preparing the pipe surface, a hold time of two hours is sufficient to minimize any hydrogen off-gassing effects.

Within the parameters of the in-field welds and simulated welds no major detrimental effects were found from hydrogen off-gassing and weld geometries. However, the higher cap height did make coatings more susceptible to damage when handling. This confirms previous GTI research which indicated that coatings often accrue damage during handling.

GTI and EWI taking into consideration the survey and testing results produced a recommendation to be distributed to various stakeholders in the pipeline industry. The summary document to be distributed is located in the *Recommendation* section of this report.

Recommendation

Protocol for Consideration of Welding/Coating Standards Committees

Prepared by: Gas Technology Institute (GTI) and Edison Welding Institute (EWI)

This research was funded in part under the Department of Transportation (DOT), Pipeline and Hazardous Materials Safety Administration's (PHMSA) Pipeline Safety Research and Development Program. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Pipeline and Hazardous Materials Safety Administration, or the U.S. Government.

Background

GTI and EWI collaborated on a DOT PHMSA co-funded project to reduce premature coating failures of in-field welded and coated pipeline sections/appurtenances. The primary reasons for coating failures include lack of coordination between the welding, preparation, and coating steps. This includes improper or inadequate surface preparation of the weld zone, coating application procedures not designed to work with the specified weld features, and/or damage as a result of handling.

Project Summary

The first and second tasks were to review existing documents to determine common industry practice when it comes to the requirements for in-field welding and coating practice. Based on the results of the literature search and an industry survey, the welding and coating protocol is summarized as follows:

- Prior to beginning work, a meeting should be held to identify areas of responsibility and timing.
- The most common acceptable range of undercut depth for both butt and fillets welds is 0 in. to 0.031 in. (0.0 mm to 0.8 mm).
- The most common acceptable range of butt weld reinforcement height is 0.031 in. to 0.063 in. (0.8 mm to 1.6 mm).
- All welding spatter, weld slag and rust bloom must be removed prior to coating.
- All oil and debris must be removed from the air supply and pipe surface.
- Surface must be grit blasted to a proper profile of 2-4 mils, unless otherwise noted by coating manufacturer.
- Coating application shall take place the same day as grit blasting, making sure that no rust has formed.
- Cured coatings must be inspected to see if it meets proper specifications.
- Coating application conditions must follow manufacture's recommendation.

The third task was to fabricate welds to evaluate the weld profile limits (weld cap height, weld undercut, etc.) and the effects of the hydrogen content in the deposited weld on pipeline coatings. The weld profile evaluation consisted of depositing several bead-on-plate welds with different levels of bead cap height, undercut, and spatter in different combinations. These welds were then coated in liquid epoxy and subjected to testing at GTI. The weld profile evaluation

trials showed that undercut up to 0.030 in. had no significant effect on the brushable grade coating's resistance to corrosion. Increasing cap height of a weld was found to thin the brushable grade coating making it more susceptible to chipping. When applying proper coating procedures, especially surface preparation, the evaluated weld geometries had no strong negative influence on a liquid two part epoxy coating performance.

Field welds were then made to evaluate the effects of hydrogen content diffusion on coating quality. For this evaluation, full girth welds using automated low hydrogen gas metal arc welding (GMAW) and shielded metal arc welding (SMAW) with 6010 electrodes (high hydrogen) were fabricated at CRC-Evans facility in Houston, TX. The completed welds were transported to Commercial Coating Services International for coating using liquid epoxy or fusion bonded epoxy (FBE). The welds were coated after hold times of 2 or 5 hours after weld completion. The coated welds were then subjected to cathodic disbondment testing to evaluate coating adhesion. The full scale tests showed no major detrimental effects from hydrogen off-gassing. However, higher cap heights did make coatings more susceptible to damage when handling as evidenced by chipping while in transport to GTI. This confirmed previous GTI research, which indicated that coatings often experience damage during handling.

Summary

The results of this research indicate that weld profile and hydrogen content of pipeline girth welds were found to have no major detrimental effects on two-part epoxy and FBE coatings. The surface preparation and proper coating application were more important factors in creating quality coatings. That being said, excessive weld cap height does cause pipeline coating to thin, which may make it more susceptible to damage during handling.

From a welding and coating perspective, this work resulted in several suggestions relevant to coating application:

- Weld undercut should be as shallow as possible, if not eliminated. The maximum acceptable undercut depth is 0.031 in. (0.8 mm) for small sections of a weld and 0.016 in. (0.4 mm) for any length along the weld.. With the proper pre-coating preparation, this undercut depth would still allow for an acceptable coating thickness.
- Weld bead height should be no more than 0.063 in. (1.6 mm), if the deposited bead height is excessively high, then the cap should be reduced and the weld toe dressed to assure a smooth transition.
- Weld spatter should be removed, prior to the application of the coating. This is normally performed by the welder or coating contractor determined by the pre-job meeting.
- The application of the coating should start no earlier than two hours after the weld is completed. Nondestructive inspection usually takes more than two hours to complete, so the proposed two hour time between weld completion and coating application should not be a constraint to the overall pipeline construction schedule.
- The pipe temperature should be at least 5°F above the dew point before coating procedures begin, it may be necessary to heat the pipe.
- Manufacturer's directions should be followed during the coating application with a focus on providing a properly prepared surface to maximize a coating's effectiveness.
- Inspection by knowledgeable personnel can identify and mitigate potential coating issues.

Recommendations

The project results provide several suggestions that could be incorporated into general pipeline construction practices that may help the overall quality of the completed and coated pipeline. It is recommended that some of these suggestions be incorporated into or reinforce current guidelines in industry standards to help achieve the overall goal of providing high quality welds.

ASME B31.4 and B31.8 currently provide guidance on the preparation of the completed welds prior to coating. It is believed that this issue should also be incorporated into other industry codes including API 1104 and CSA Z662 to further highlight the importance of weld preparation for proper coating. For example suggested wording could be included into existing standards:

"The completed weld shall be thoroughly brushed and cleaned including removing all weld spatter. If applicable, any irregularities that could protrude through the pipeline coating should be removed."

This wording mirrors similar guidance that is provided in ASME B31.4 and B31.8. The suggested wording could be included in an existing section of API 1104, such as Section 7.8.2 and in CSA Z662 Section 9.3.2

To facilitate this recommendation the final public report can be added as a reference (when it becomes available at: <http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=208>).

Respectfully,

Michael Miller, GTI
847-768-0949

Appendix A: Welding Terminology

A variety of standard⁶ and nonstandard terms (a.k.a., industry jargon) are used to describe different aspects of welding. Each industry sector, like the pipeline industry, has its own unique industry jargon specific to welding. This report uses standard American Welding Society (AWS) welding terms and definition. This section defines the standard welding vocabulary used in this report to eliminate any confusion between standard terminology and commonly used industry jargon.

AWS. The American Welding Society is the leading producer of codes, specifications, guides, recommended practices, and welding/joining books for the worldwide welding industry. Over 1,400 professionals currently serve on more than 200 AWS technical committees, dedicated to the development of consensus standards under the rules of the American National Standards Institute (ANSI). Accredited by ANSI to publish American National Standards on welding, AWS administers the USA technical advisory groups to ISO/TC44 (Welding and Allied Processes) and most of the ISO/TC44 subcommittees, as well as, being the Authorized National Body (ANB) to the International Institute of Welding (IIW).

FCAW. The standard AWS letter designation for flux-cored arc welding is FCAW. A process schematic of FCAW is shown in Figure 48. FCAW features a flux filled tubular wire electrode that is fed through the welding torch and melts to become the majority of the deposited weld bead.

GMAW. The standard AWS letter designation for gas metal arc welding is GMAW. The most common industry jargon for GMAW is "MIG". A process schematic of GMAW is shown in Figure 48. GMAW features a solid wire electrode that is feed through the welding torch and melts to become the majority of the deposited weld bead.

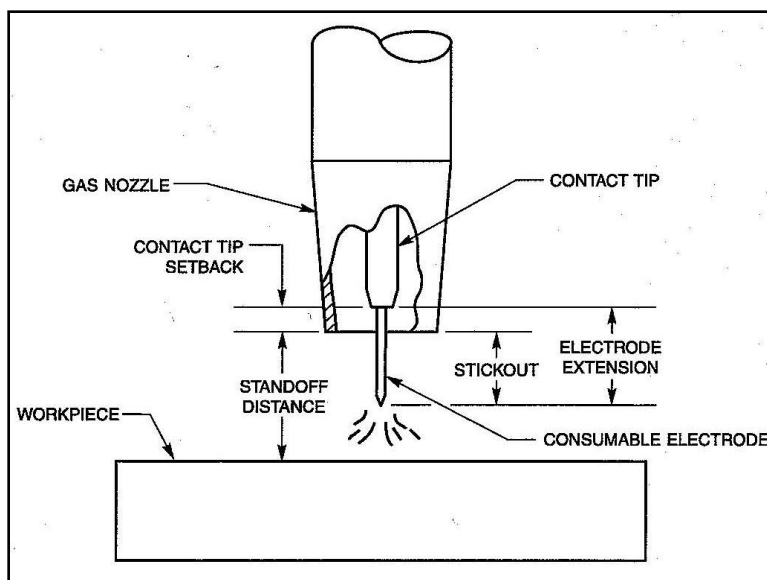


Figure 48: GMAW and FCAW Process Schematic⁶

SMAW. The standard AWS letter designation for shielded metal arc welding is SMAW. This process is most commonly called "stick welding". This manual welding process is the least productive of the processes discussed in this report. It has a deposition rate that is less than half that of GMAW and

FCAW depending on the welding parameters selected. A process schematic of SMAW is shown in Figure 49.

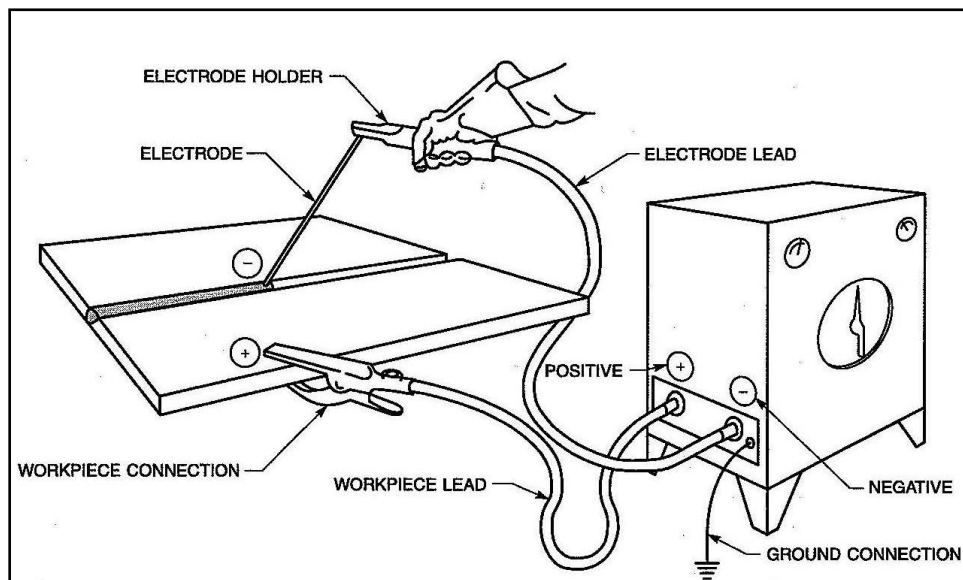


Figure 49: SMAW Process Schematic⁶

Constant Voltage. GMAW, FCAW, and submerged arc welding (SAW) power sources are constant-voltage (CV) machines. A CV power supply, "has means for adjusting the load voltage and has a static volt ampere curve that produces a relatively constant load voltage. The load current, at a given load voltage, is responsive to the rate at which a consumable electrode is fed into the arc."⁷ A CV power supply combined with a consumable electrode delivered at constant wire feed speed, creates a self-regulating system that tends to maintain a constant arc length. This is a mature technology called automatic voltage control (AVC) and is the foundation of automatic welding systems including the one developed for this project.

Weld Joint Type. The weld joint type is based on the relative orientation of the plates (or members) being welded together. There are five basic weld joint types: butt, T-, corner, lap, and edge (Figure 50).

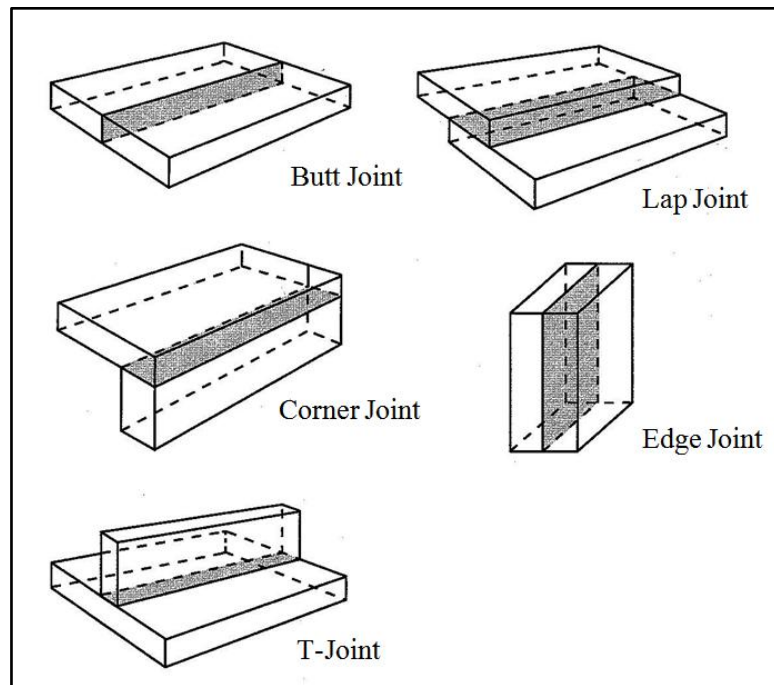


Figure 50: Weld Joint Types⁶

Fillet Weld. A weld that is roughly triangular in cross section that joins two plates together that are at right angles to each other. A typical fillet weld is shown in Figure 51.

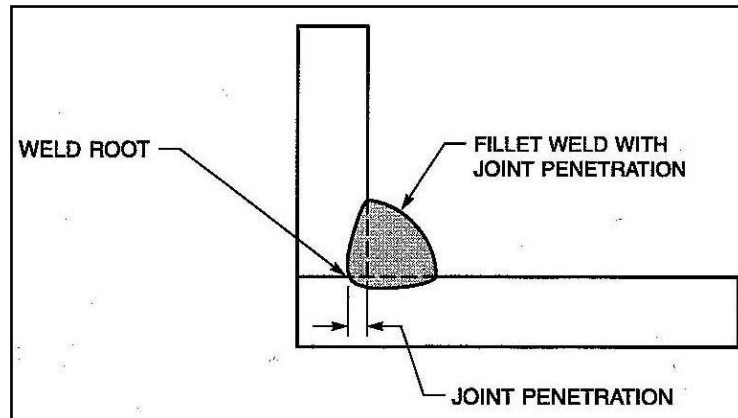


Figure 51: Typical Fillet Weld⁶

Groove Weld. A weld made in a groove that joins two plates together. The plates being joined are generally in the same plane or parallel to each other. The groove can have many different configurations, depending on how the edges are prepared before welding. A typical groove weld is shown in Figure 52. This particular weld is a V-groove made from one side, i.e., a single sided V-groove weld.

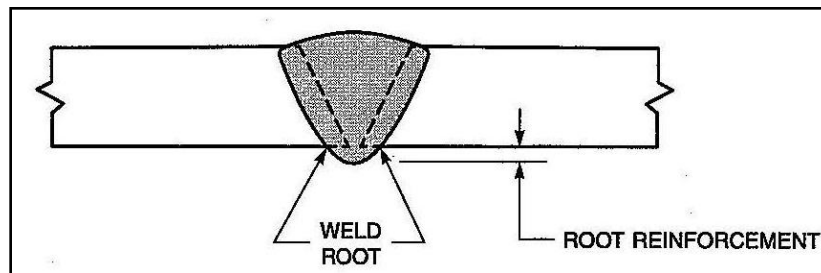


Figure 52: Typical Single Sided V-Groove Weld⁶

Bead-on-Plate Weld. The welds made for the geometry affect evaluations were bead-on-plate, which means that a weld bead was made on a plate. Bead-on-plate welds do not have a joint type (i.e., a "fillet" or "groove" joint is not part of the specimen), see Figure 53. Bead-on-plate welds can be made in all welding positions (see Welding Positions). The welding positions for bead-on-plate welds can most easily be described in terms of groove welding positions. A "stringer" technique was used to produce the bead-on-plate welds for this project (see Stringer Bead).

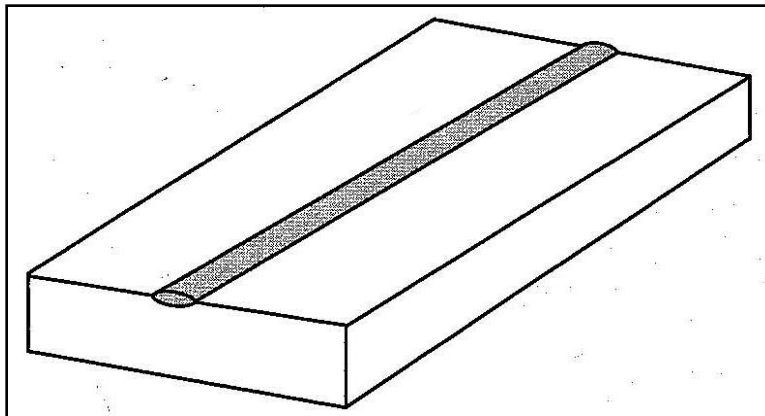


Figure 53: Typical Bead-on-Plate Stringer Weld⁶

Welding Position. Welding position is the 3D orientation of the weld joint during the deposition of weld metal. Figure 54 is the official AWS diagram that defines the ranges for welding positions for a T-joint fillet weld, typical of that which is used to attach full-encirclement sleeves and hot tap connections. Figure 55 is an illustration of flat, horizontal, vertical, and overhead fillet welding positions and their corresponding AWS designations. Figure 56 is the official AWS diagram that defines the ranges for welding positions for a groove weld, typical of that which is used to attach pipe sections to each other. Figure 57 is an illustration of flat, horizontal, vertical, and overhead groove welding positions and their corresponding AWS designations.

TABULATION OF POSITIONS OF FILLET WELDS			
POSITION	DIAGRAM REFERENCE	INCLINATION OF AXIS	ROTATION OF FACE
FLAT	A	0° TO 15°	150° TO 210°
HORIZONTAL	B	0° TO 15°	125° TO 150° 210° TO 235°
OVERHEAD	C	0° TO 80°	0° TO 125° 235° TO 360°
VERTICAL	D	15° TO 80°	125° TO 235°
	E	80° TO 90°	0° TO 360°

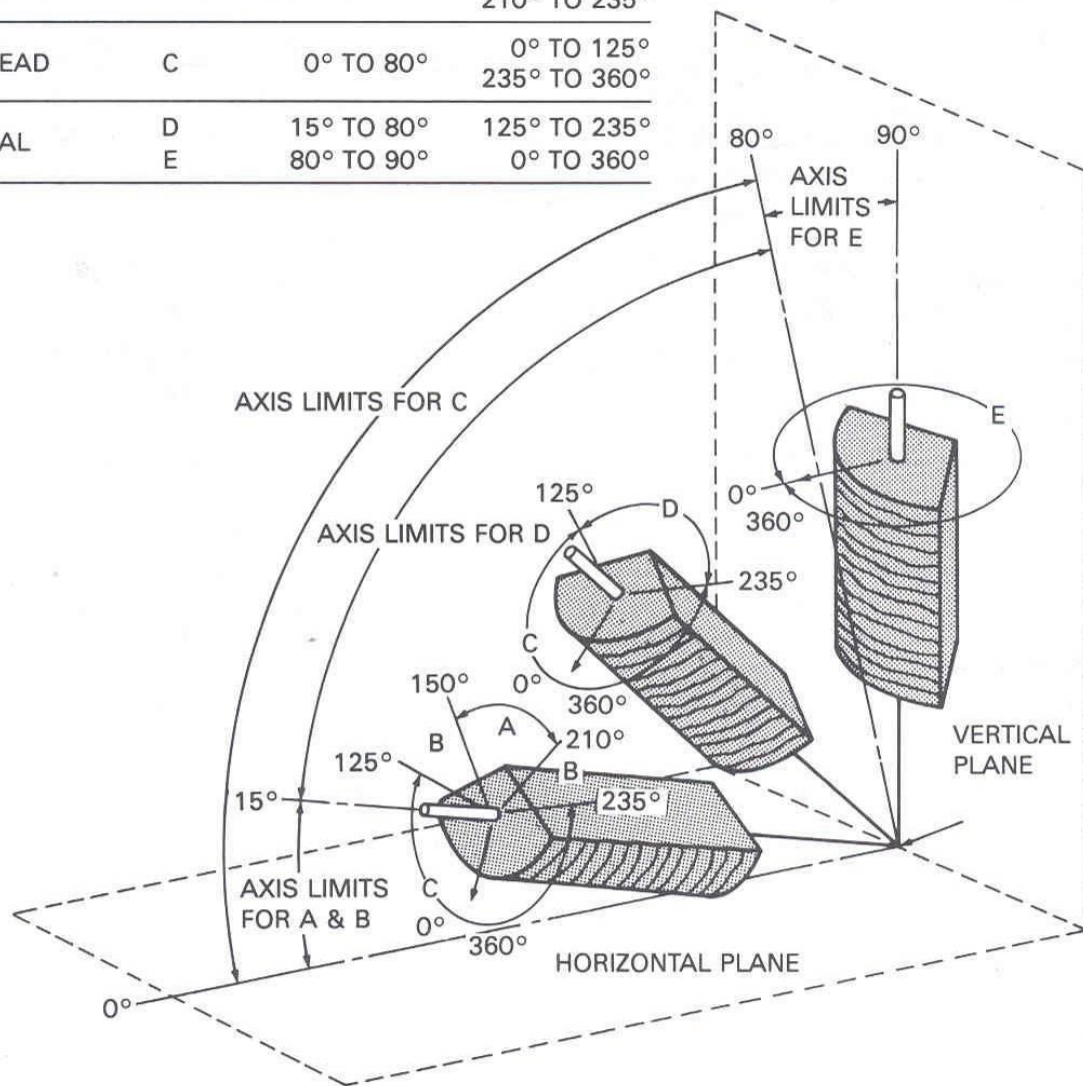
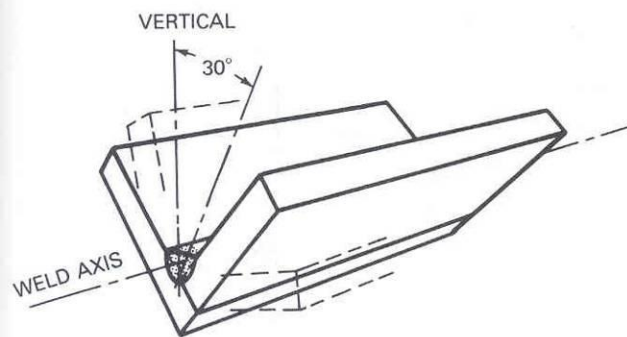
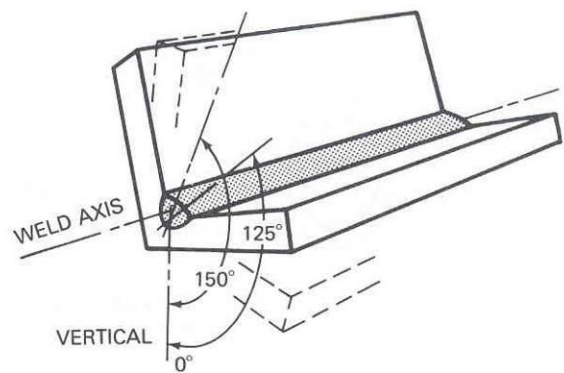


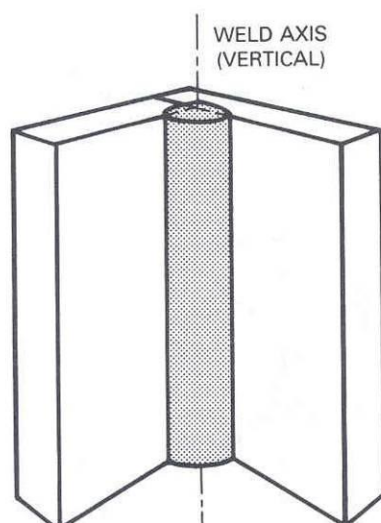
Figure 54: Diagram of Fillet Welding Position Ranges on Plate⁸



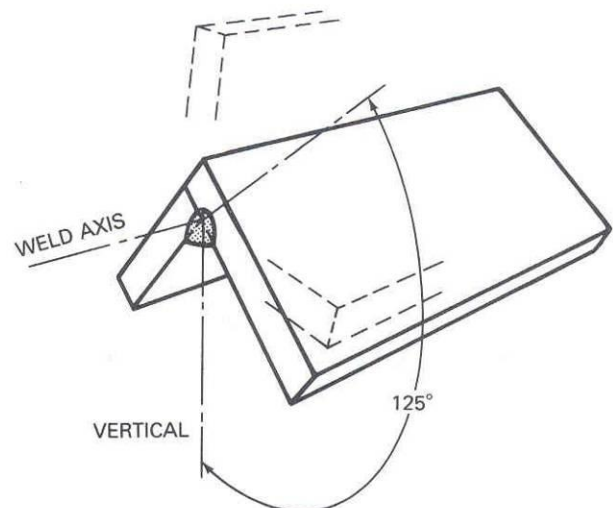
Flat Position (1F)



Horizontal Position (2F)



Vertical Position (3F)



Overhead Position (4F)

Figure 55: Fillet Welding Positions and their Designations⁹

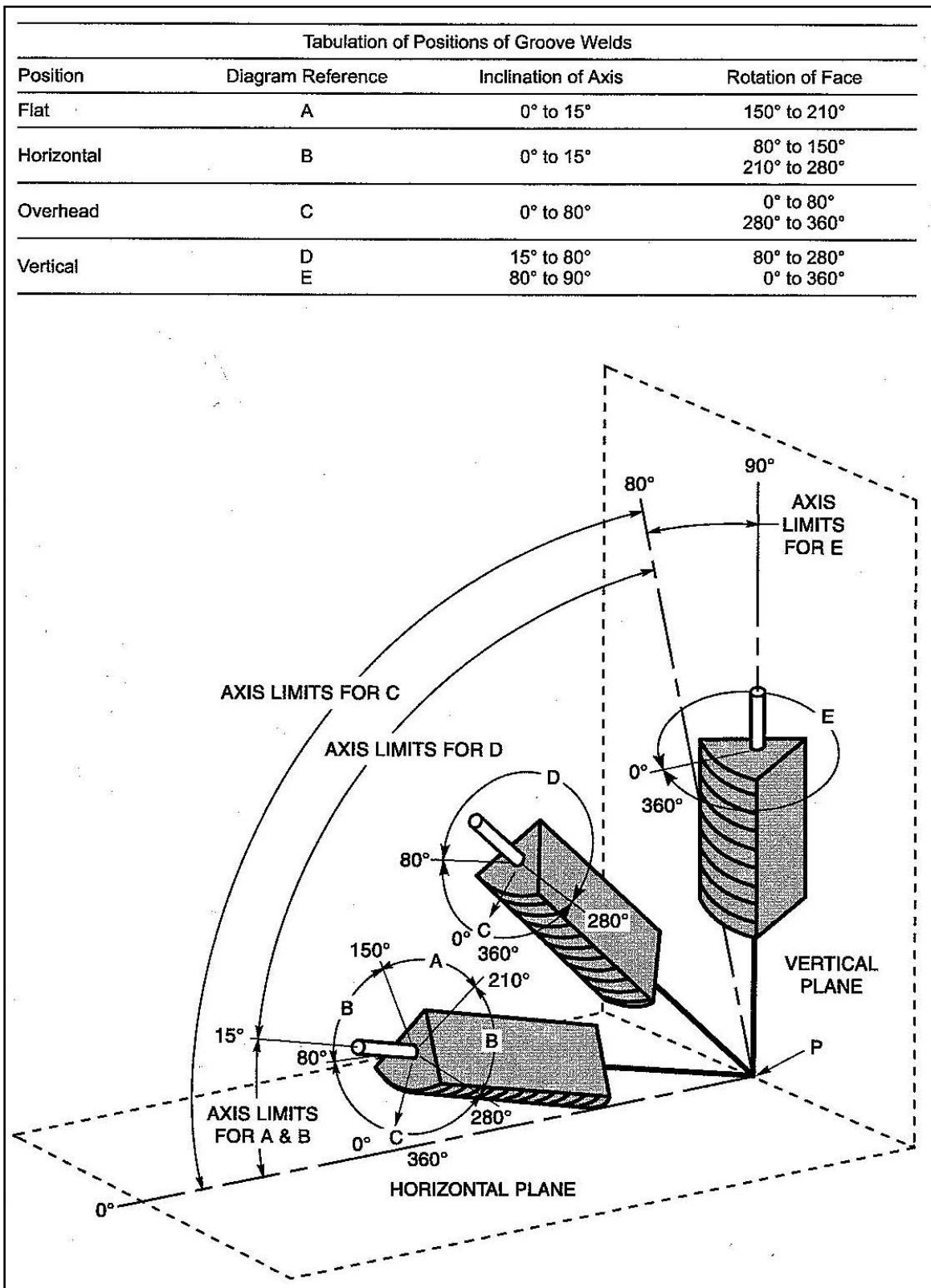


Figure 56: Diagram of Groove Welding Position Ranges on Plate⁶

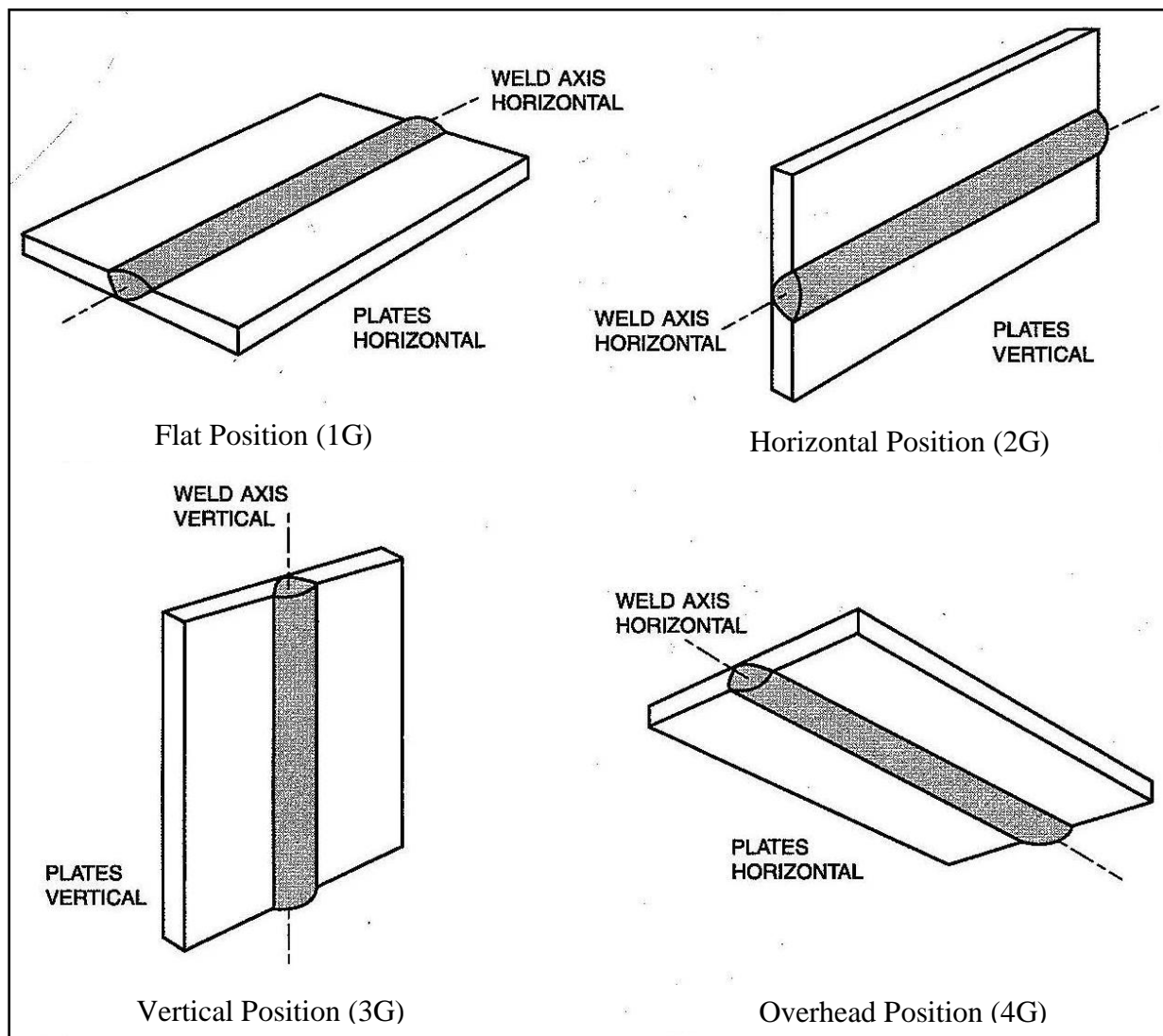


Figure 57: Groove Welding Positions and their Designations⁶

Downhill Welding. This is the AWS preferred term for welding vertically downward; the nonstandard term for this progression is vertical down. It describes welding on a pipe from 12 to 6 o'clock.

Uphill Welding. This is the AWS preferred term for welding vertically upward; the nonstandard term for this progression is vertical up. It describes welding on a pipeline from 6 to 12 o'clock.

Welding In Position. Depositing welds in the flat or horizontal position is welding "in position". Welding in position tends to have the greatest productivity, depositing (on average) twice as much welding wire as welding out-of-position per unit time for the same welding process. When welding in

position, higher currents and voltages can be used; therefore, you can deposit the maximum amount of weld metal per unit time.

Welding Out-of-Position. Depositing welds in the vertical or overhead position is welding "out-of-position." Welding out-of-position is less productive, as 60% less weld metal is typically deposited per unit time as compared to welding in position for the same welding process. When welding out-of-position lower currents and voltages must be used to keep the molten weld pool in the joint; therefore you cannot deposit the maximum amount of weld metal per unit time.

Weave. A welding technique where the welder (or the automatic welding system) moves the arc in a repetitive pattern as weld metal is deposited in the joint. Weaving is standard practice in out-of-position welding in order to counter the effects of gravity and keep weld metal in the joint as it solidifies. A typical uphill weave pattern (for a fillet weld) is illustrated in Figure 58.

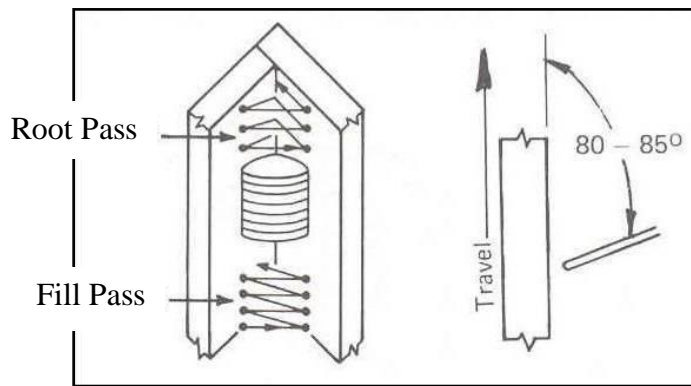


Figure 58: Typical Weave Pattern for Vertical-Up Welding¹⁰

Stringer Bead. A weld bead made without weaving (Figure 53).

Work Angle. The work angle refers to the angle of the torch in relationship to the perpendicular faces of the tee joint shown in Figure 59. The ideal angle is typically 45°.

Travel Angle. The travel angle refers to the angle of the tip in relationship to the travel direction (Figure 59). The ideal is to have the tip perpendicular to the travel direction, which is 90°. In manual welding a push or drag angle can be used within the travel angle range of 70° to 110°.

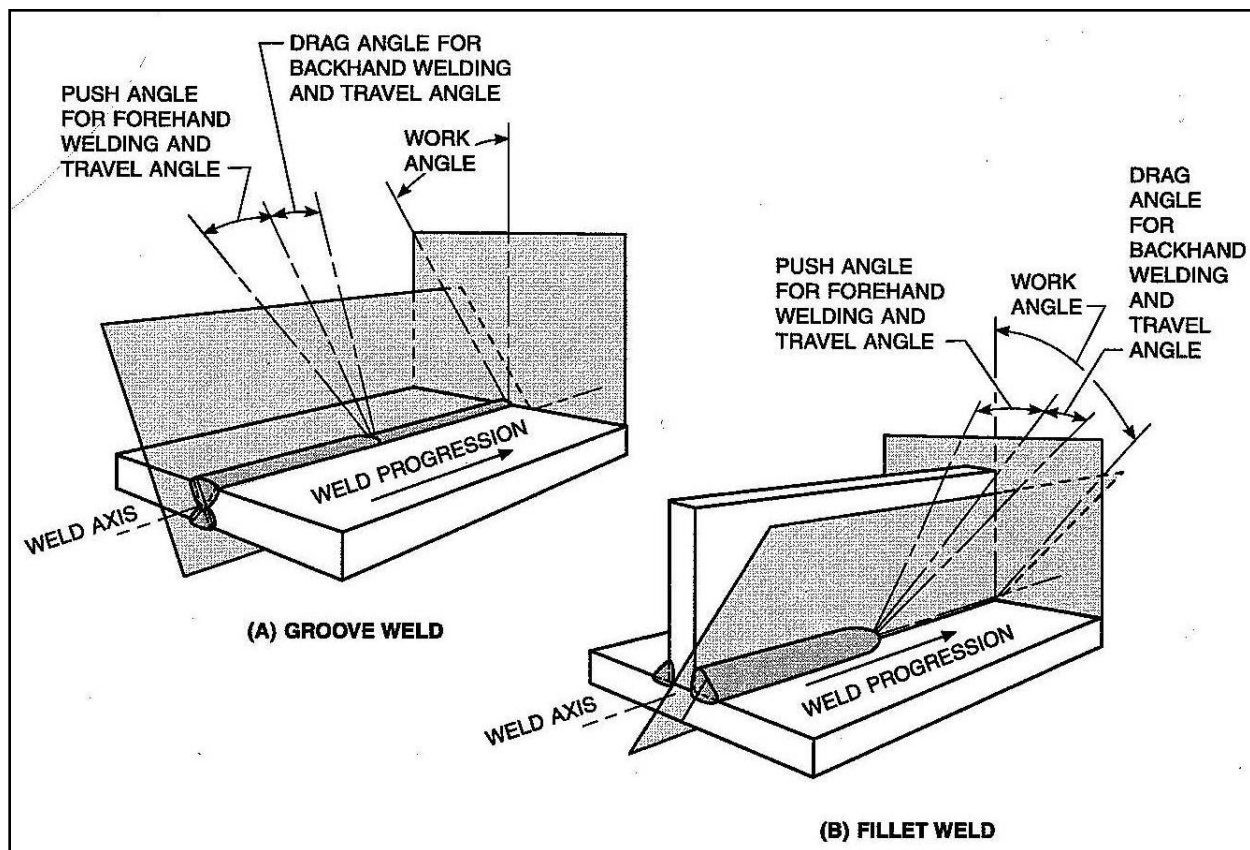


Figure 59: Work and Travel Angles for Groove and Fillet Welds⁶

Weld Attribute. A geometric feature of a weld. A weld attribute may describe a particular physical attribute of a weld (e.g., bead height, length, width, weave pattern, etc.) or it may describe a discontinuity or a defect (see **Discontinuity** and **Defect**).

Discontinuity. An interruption of the typical structure of a material, such as, a lack of homogeneity in its mechanical, metallurgical, or physical characteristics. A discontinuity is an acceptable flaw according to the given welding code. A discontinuity is not technically a defect; whether a discontinuity is a defect is dictated by the given welding code (see **Defect**).

Defect. A discontinuity that by itself makes a weld unable to meet minimum quality acceptance criteria designated by the applicable welding code or a series of discontinuities, the accumulated effect of which makes a weld unable to meet minimum quality acceptance criteria as defined by the applicable welding code. A defect is a flaw that results in a rejected weld according to the given welding code. For example, a welding code states that any crack exceeding 0.125-in. (3.2-mm) in length found in a 12-in. (305-mm) length of a weld is a defect and is thereby unacceptable. Cracks less than 0.125-in. (3.2-mm) in length found in a 12-in. (305-mm) length of weld are therefore considered discontinuities and are acceptable according to the code.

Bead Height. Bead height is a weld attribute that describes the perpendicular distance from the top surface of the base material to the top of the face reinforcement as shown in Figure 60.

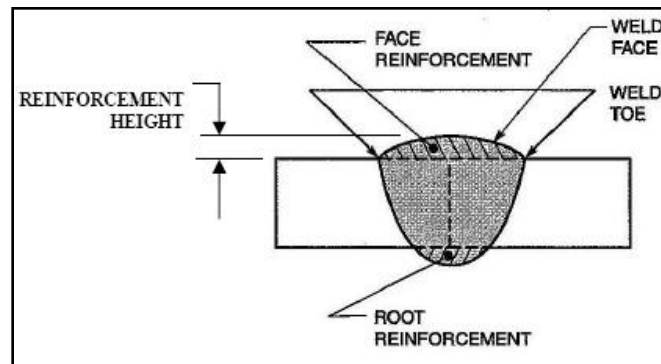


Figure 60: Groove Weld Reinforcement Height

Spatter. Metal particles expelled during GMAW, FCAW or SMAW welding that do not form part of the weld. These particles adhere to the base metal at various distances from the weld. They vary in size and quantity, as well as in the intensity of their adherence to the base metal. Spatter is generally undesirable.

Appendix B: Survey Questions and Results

A 1% response rate is typical for unsolicited surveys. This survey was sent to a total of 581 Email addresses; a total of 101 responses were received, thus representing a 17% response rate.

The raw survey data from SurveyMonkey.com was downloaded into an Excel file. The raw data was then transferred to a master Excel file designed to analyze the data and to convert it into the most appropriate form for reporting purposes. In the following narrative, survey data, analysis and discussions are organized by survey question (shown in **bold**).

1. Which process is your company associated with?

The survey was organized so the respondent was first asked if they were associated with "welding" or "coating". Depending on their response, they were then lead thru a series of questions specifically designed for either welding or coating processes (i.e., welding people were sent directly to question 2; coating people were sent directly to question 46). Both welding and coating people were then asked generic questions common to both processes (starting with question 57). A total of 101 survey responses were received; 75% represented welding operators and 25% represented coating operators.

In the additional comments section for question 1, one company indicated that they are involved in both welding and coating processes. Three responses to question 62 indicated that two additional companies are also involved with both welding and coating processes. It is uncertain to what extent making respondents choose between welding and coating may have affected the results of the survey.

2. What welding process or processes do you use to make butt welds? Select all processes that apply.

The respondents that selected "welding" were directed to question 2. The majority of respondents use shielded metal arc welding (SMAW) (48%), followed by gas metal arc welding (GMAW) (27%), and flux cored arc welding (FCAW) (19%). A small percentage of respondents use gas tungsten arc welding (GTAW) (7%) or submerged arc welding (SAW) (6%) as shown in Figure 61.

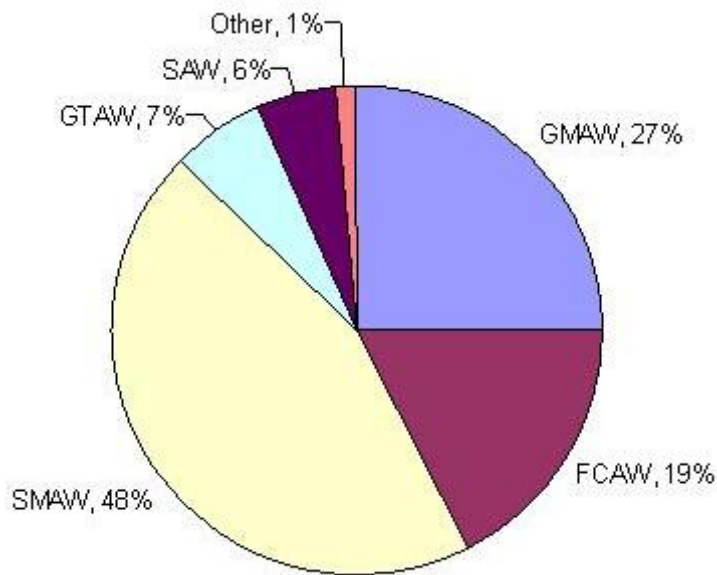


Figure 61: Butt Welding Processes Used by Respondents

1% of the respondents indicated that they also use the following other welding processes:

- GTAW/SAW combination.
- Pulsed GMAW (GMAW-P).
- Explosion welding (EXW).
- Oxyfuel gas welding (OFW).

The responses to Question 2 are typical of what is expected in the pipeline welding. Since a majority of pipeline welding is performed in remote locations with limited resources, the use of more sophisticated welding power supplies, such as GMAW, FCAW and GTAW power supplies, is very limited. SMAW power supplies are very mobile and adaptive to the every changing welding environment (e.g. a single welder with a diesel-drive motor generator). GMAW has more recently been used on larger diameter (e.g. 36-in and up) pipelines because the increased productive of the welding process over comes the increased costs required needed for fabricating GMA welds.

3. **Does your company use a nondestructive evaluation (NDE) method on the outside diameter (OD) to inspect butt welds for undercut? (Please note: NDE includes visual inspection of physical measurements.)**

Shortly after the survey was released, a large percentage of respondents indicated that did not use NDE methods. Feedback from a survey respondent¹¹ indicated that industry jargon often assumes NDE includes methods other than visual inspection; when in fact, visual inspection is an NDE method. Consequently, the last parenthetical sentence was added to this question to clarify the fact that visual inspection is an NDE process and that it includes taking physical measurements. Survey respondents were then sent a new Email clarifying the definition of NDE and were asked to modify their responses accordingly. The survey results then changed to align more with what was expected: 97% of respondents indicate that they use NDE to inspect for butt weld undercut; 3% do not.

4. What NDE process or processes do you use to inspect butt weld undercut?

The majority of respondents (48%) indicated that they use visual inspection to detect butt weld undercut on the OD of pipe. For inspecting undercut on the inside diameter (ID) of pipe, 41% indicated that they use radiography and 11% use ultrasonics (see Figure 62).

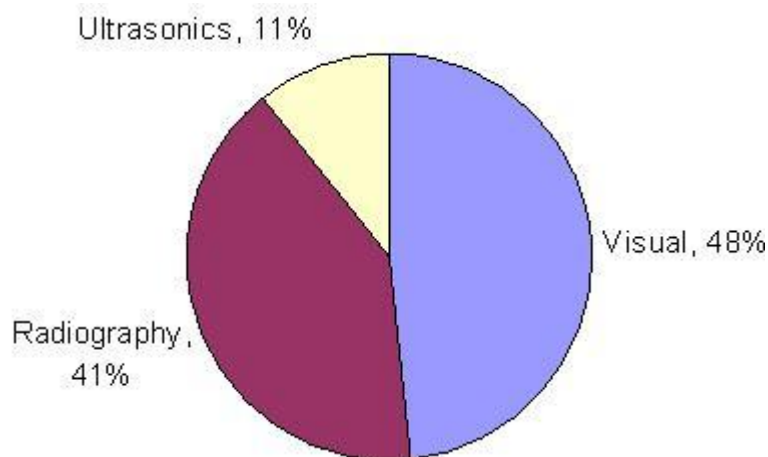


Figure 62: NDE Processes Used to Find Butt Weld Undercut

5. Which process is the primary NDE process used to measure butt weld undercut?

The majority of respondents (60%) indicated that they use visual inspection as the primary process to inspect for butt weld undercut on the OD of the pipe. 37% indicated that they use radiography on the ID. Two respondents (3%) indicated that their companies use a combination of radiography and ultrasonics for ID inspection. These results are graphically displayed in Figure 63.

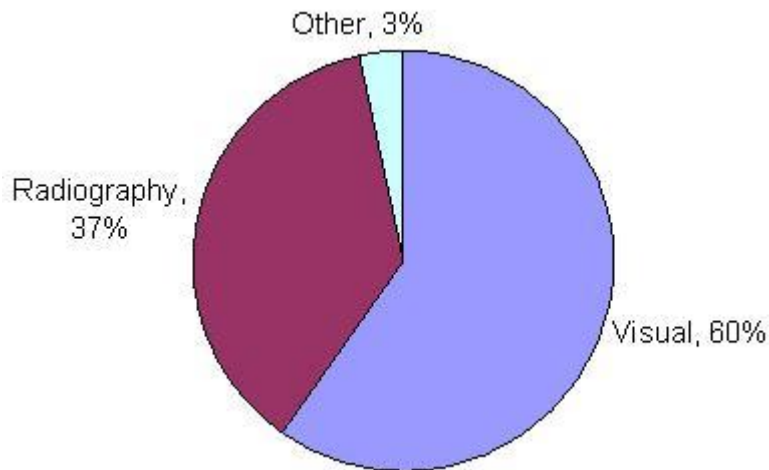


Figure 63: Primary NDE Process Used to Measure Butt Weld Undercut

6. To define acceptable limits for butt weld undercut, do you use an Industry Code or an In-House Code?

The vast majority of respondents (86%) indicated that they use an industry code to define acceptable limits for butt weld undercut; 14% use an in-house code.

7. Please describe acceptable limits for undercut according to your In-House or Other code.

While the responses to this question exhibited some commonality, it was not possible to graph the responses. Individual responses are listed below.

- Varies depending on the project.
- Undercut shall be less than 1/64-in. or 12.5%, whichever is smaller.
- For projects using an alternative acceptance criteria, *i.e.*, CSA Z 662 appendix K, it is generally <1-mm = 10% of pipe circumference.
- For cross country pipeline, API 1104. For station piping only: Undercutting Butt Weld (EU & IU) Fillet Weld (EU Only) IF THE DEPTH IS: Over 1/32-in. or over 12.5% of wall thickness - none acceptable Over 1/64-in. or over 6% of wall thickness, but not over 1/32-in. or 12.5% of wall thickness - Total of IU plus EU shall not exceed 2-in. in any 12-in. length or 1/6 of the weld length 1/64-in. or less and 6% or less of wall thickness - acceptable.
- We do not allow any undercutting.
- The undercut requirement varies greatly due to the operating conditions, design considerations etc. Most projects require the undercut limits of API 1104, but some applications require no undercut external or internal.

8. Select all industry codes that apply and/or fill in the blank if appropriate.

The majority of respondents (31%) indicated that they use API 1104; 17% use ASME B31.8, 15% use ASME B31.4, 14% use ASME IX, and 9% use AWS D1.1. The distribution of code usage is found in Figure 64.

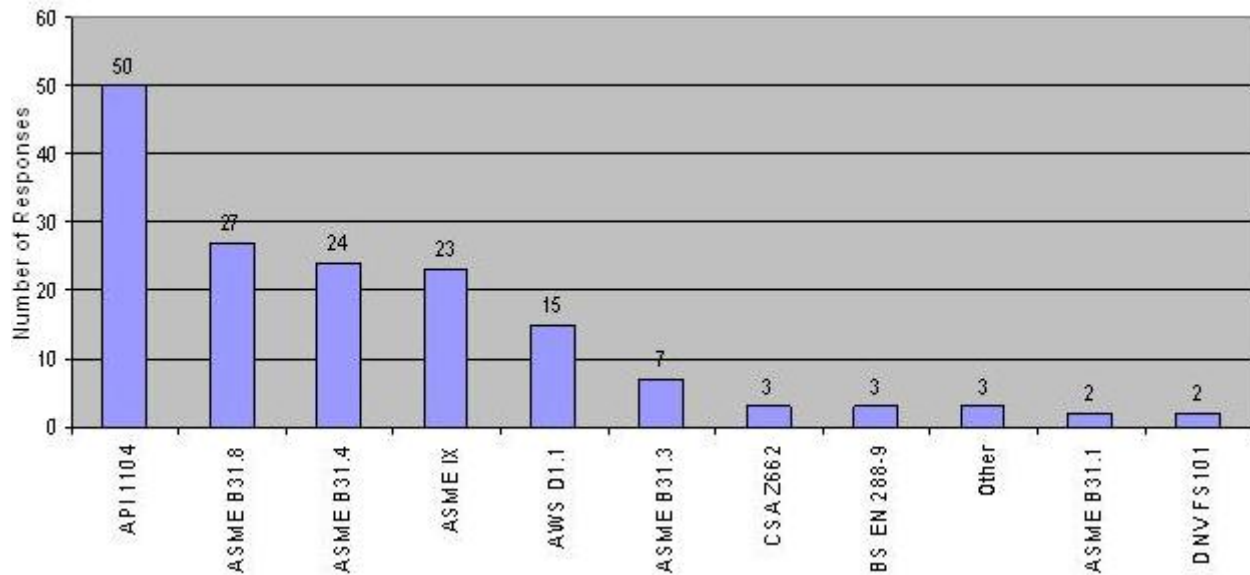


Figure 64: Industry Codes Used to Define Butt Weld Undercut

Three respondents indicated that they use codes other than those listed. Their individual responses are listed below.

- AS2885, Australian Standard 'Pipelines - Gas and Liquid Petroleum'
- EEMUA 158
- BS 4515 (although related to EN 288-9)

9. Does your company use a NDE method on the OD to inspect for butt weld reinforcement height?

The vast majority of respondents (90%) use an NDE method to inspect the OD for butt weld reinforcement height; 10% do not.

10. What NDE process or processes do you use to inspect for OD butt weld reinforcement height?

The vast majority of respondents (72%) use visual inspection; 27% use radiography, and 1% use ultrasonics (see Figure 65). Again, radiography and ultrasonics are used to inspect the pipe ID.

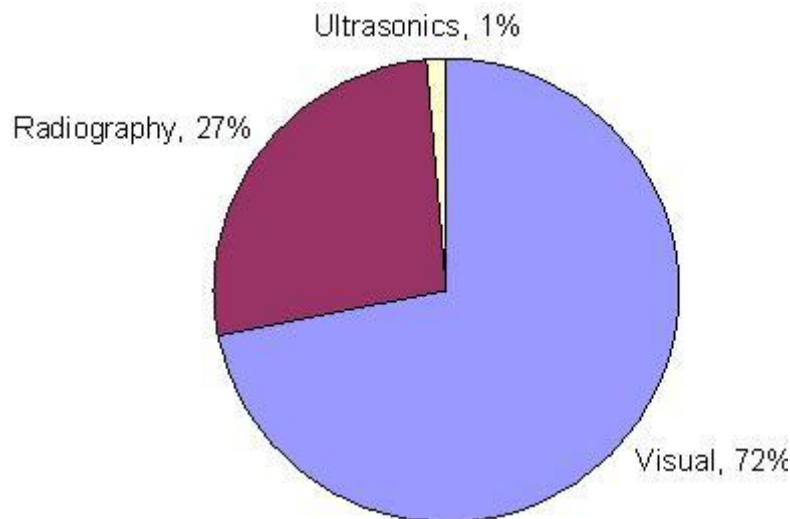


Figure 65: NDE Processes Used to Determine OD Butt Weld Reinforcement Height

11. Which process is the primary NDE process used to measure OD butt weld reinforcement height?

The vast majority of respondents (89%) indicated they primarily use visual inspection; 11% indicated radiography. Again, radiography is used to measure the ID.

12. To define acceptable limits for butt weld reinforcement height, do you use an Industry Code or an In-House Code?

The vast majority of respondents (84%) indicate that they use an industry code; 16% use in-house codes. The results are graphically shown in Figure 66.

13. Select all Industry Codes that apply and/or fill in the blank if appropriate.

The majority of respondents (34%) indicated that they use API 1104; 15% use ASME B31.8, 15% use ASME IX, 13% use ASME B31.4, and 10% use AWS D1.1. The distribution of code usage is found in Figure 66.

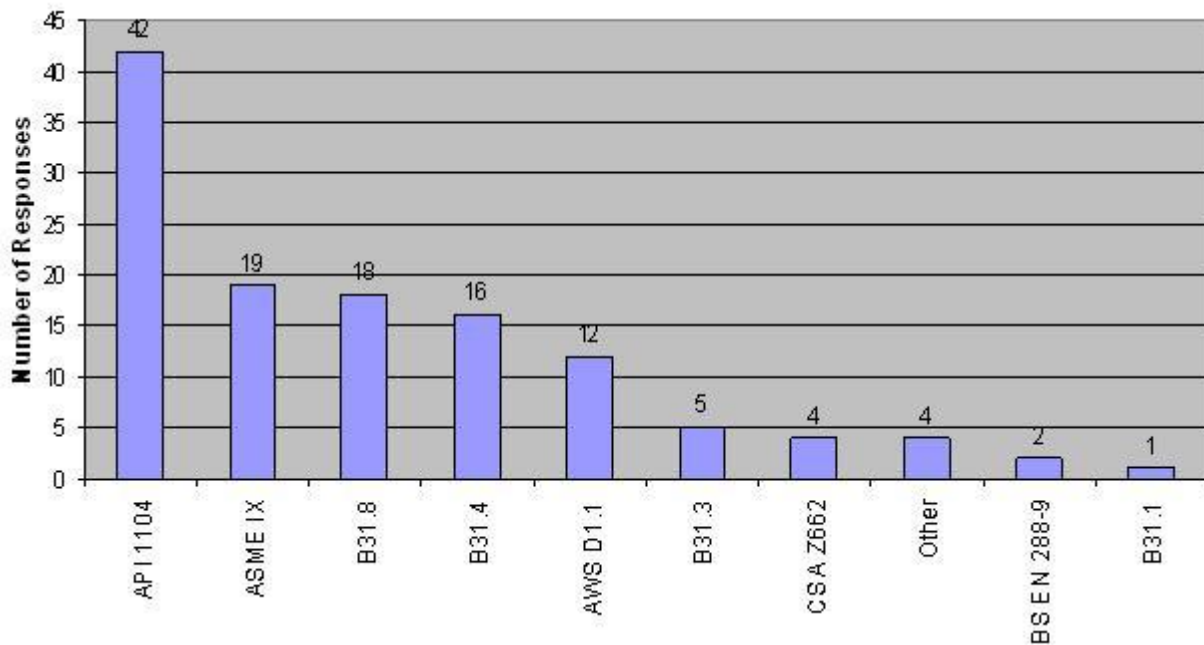


Figure 66: Industry Codes Used to Define Butt Weld Reinforcement Height

Four respondents indicated that they use codes other than those listed. Their individual responses are listed below.

- AS2885.
- Company requirements also.
- EEMUA 158.
- DNV OS-F101, BS 4515.

14. Describe acceptable limits for weld reinforcement height according to your In-House or Other code.

The responses to this question exhibited some commonality; however, it was not possible to graph the responses. Individual responses are listed below as bullet points.

- Depends on individual project.
- Minimum 1/32-in., maximum 1/16-in.
- Butt weld reinforcement height shall not be less than 1/32-in.
- For normal pipelines 3-mm (1/8-in.) Doe SCRs 1.6-mm (1/16-in.).
- Weld Reinforcement (where the thinner component is 1/2-in. and under) - 1/8-in. Maximum (1/16-in. desired).

- Weld Reinforcement (where the thinner component is above 1/2-in.) - 3/16in. maximum (1/16-in. desired).
- Acceptable if: Up to 0.125-in. for wall thicknesses of 0.500-in. and less. Up to 0.188-in. for wall thicknesses over 0.500-in.
- Depending on the application, we use API 1104 requirements up to grinding the reinforcement off. We require a 125 rms surface finish if ground.

15. Does your company use a NDE method on the OD to inspect for spatter?

The majority of respondents (74%) use NDE to inspect the OD for butt weld spatter; 26% do not.

16. What NDE process or processes do you use to inspect for butt weld spatter?

The majority of respondents (84%) use visual NDE to inspect the OD for butt weld spatter; 16% do not.

17. Which process is the primary NDE process used to identify butt weld spatter?

The vast majority of respondents (93%) use NDE to inspect the OD for butt weld spatter; 5% use radiography exclusively, again for ID inspection only (see Figure 67). The one respondent that indicated they use a combination of radiography and visual inspection techniques (visual on the OD and radiography on the ID).

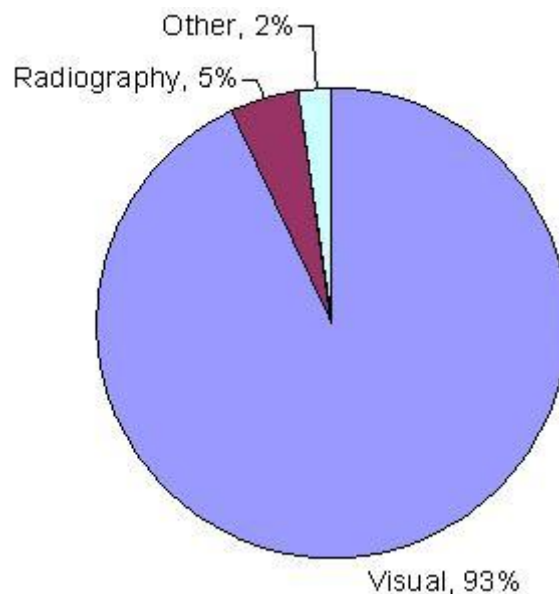


Figure 67: Primary NDE Processes Used to Determine Acceptable Butt Weld Spatter

18. To define acceptable limits for spatter, do you use an Industry Code or an In-House Code?

The majority of respondents (74%) use an industry code; 26% use an in-house code.

19. Select all Industry Codes that apply and/or fill in the blank if appropriate.

The majority of respondents (30%) indicated that they use API 1104; 16% use ASME IX, 12% use ASME B31.8, 12% use ASME B31.4, and 9% use AWS D1.1. The remaining code usage is found in Figure 68.

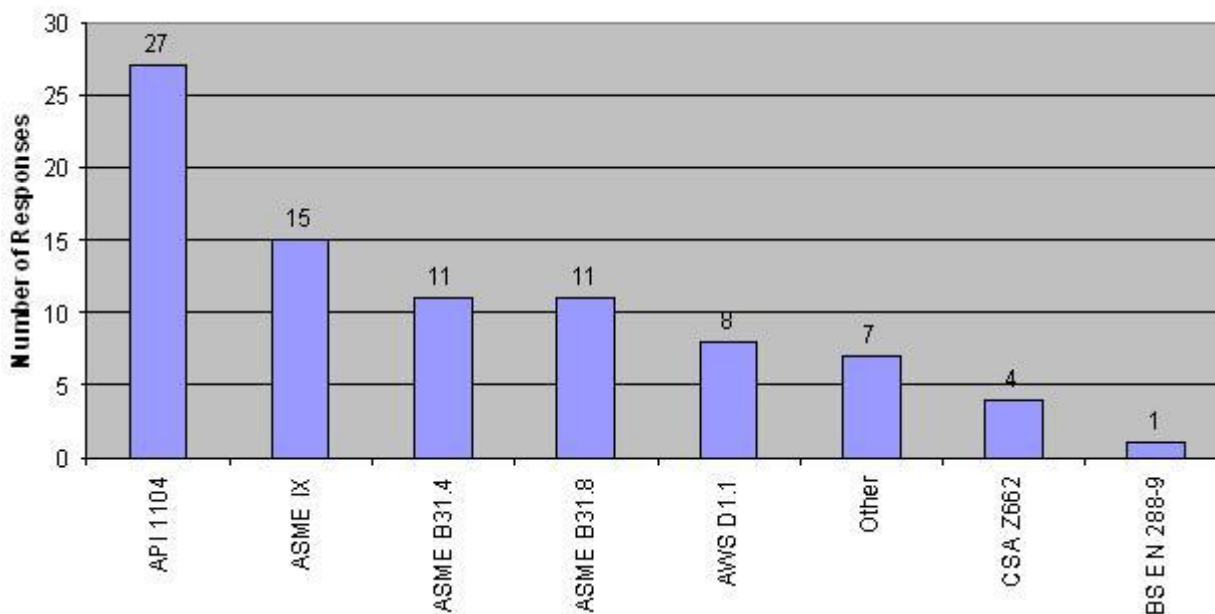


Figure 68: Industry Codes Used to Define Acceptable Butt Weld Spatter Amounts

20. Describe acceptable limits for spatter according to your In-House or Other code.

The majority of respondents indicated that no spatter was allowed per their in-house code. Individual responses are listed below as bullet points to illustrate the differences between companies.

- None present.
- Remove all spatter with a wire buff or file.
- All weld spatter should be removed prior to inspection and coating.
- None allowed.
- Spatter must be removed.
- Workmanship. It should be as free of spatter as possible.

- Special requirements for weld/base metal cleaning and preparation for subsequent corrosion protection coating applications may be required by specification, code, drawings, etc. Inspector then refers to project/job specific requirements for inspection acceptance criteria.
- All spatter will be removed.
- Spatter is acceptable provided it can be removed by grinding without reducing wall thickness beyond acceptable limits and there is no evidence of arc burns. Arc burns are removed, typically by cylinder cut out.
- Workmanship standard.
- None allowed.

6.1 Summary of the Butt Weld Inspection Criteria

The responses to questions dealing with applicable standards are what were expected because the majority of the survey recipients were American based pipeline operator and pipeline companies. API and ASME are American based standards for pipeline construction. The scope of API 1104 covers field welding of both liquid and gas transmission pipelines. ASME B31.8 is for construction of gas transmission pipelines and ASME B31.4 is for construction of liquid transmission pipelines. Both B31.8 and B31.4 refer to ASME Section IX for welding procedure and welder qualification.

Visual inspection was the main NDE method used to determine the presence and the amount of undercut, reinforcement and weld spatter. Visual inspection is a good technique to inspect and measure weld discontinuities on the OD of the pipe but it may not be applicable to inspecting the ID surface of the pipe. The typical NDE methods used to find volumetric imperfections and discontinuities on the ID surface of the pipe is ultrasonic or radiographic inspection. These inspection techniques have difficulty determining the extent of surface discontinuities since the magnitude of these discontinuities are small relative to the thickness being inspected. For this reason, surface discontinuities (e.g. undercut, excessive bead height) are typically measure manual for acceptance if the surface is accessible.

It is important to note that the NDE required is directly affected by the design of the pipeline. If the design of the pipeline is a strain-based design then there are tighter tolerances for imperfections that need to be met. This type of design lends to ultrasonic or radiographic inspection. Less critical/ low pressure pipeline designs may only require a visual inspection during welding to assure proper weld quality. For this same reason, many of the acceptance criteria is slightly more strict than typical industry codes.

21. What welding process or processes do you use to make fillet welds?

The majority of respondents use SMAW (57%), followed by GMAW (21%), FCAW (16%) and GTAW (6%) (see Figure 69). One respondent indicated that he uses a GTAW/SMAW combination. This is not a surprise for the same reasons discussed as a result of the responses to Question 2.

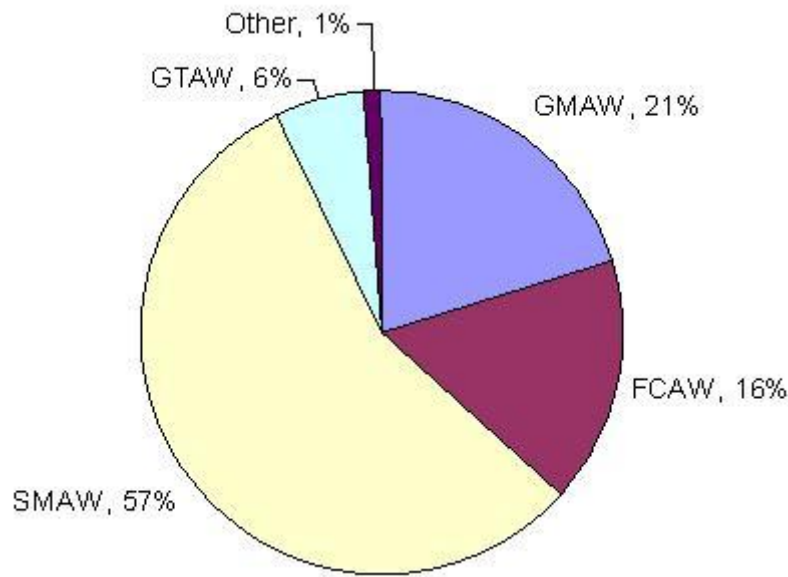


Figure 69: Fillet Welding Processes Used by Respondents

22. Does your company use an NDE method on the OD to inspect fillet welds for undercut?

The overwhelming majority of respondents (97%) use an NDE method to inspect for fillet weld undercut; 7% do not.

23. What NDE process or processes do you use to inspect fillet welds for undercut?

The majority of respondents (68%) use visual inspection, followed by magnetic particle (11%), liquid penetrant (8%), radiography (8%), and ultrasonics (4%) (Figure 70).

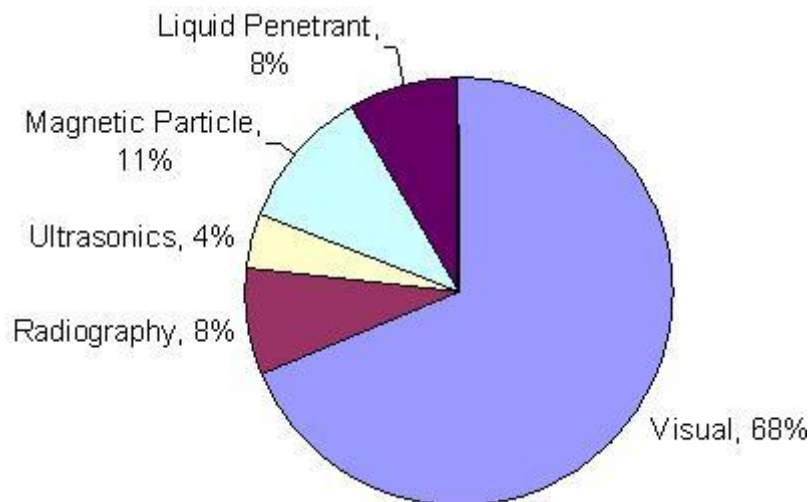


Figure 70: NDE Processes Used to Find Fillet Weld Undercut

24. Which process is the primary NDE process used to measure undercut on fillet welds?

The vast majority of respondents (84%) use visual inspection, followed by magnetic particle (7%), liquid penetrant (5%), and radiography (4%) (see Figure 71).

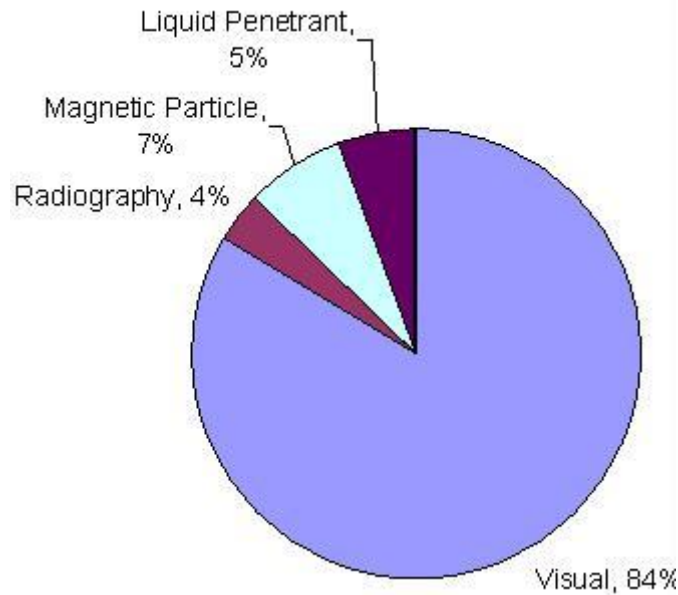


Figure 71: Primary NDE Process Used to Find Fillet Weld Undercut

25. To define acceptable limits for fillet weld undercut, do you use an Industry Code or an In-House Code?

The majority of respondents use an industry code to define acceptable limits for fillet weld undercut; 13% use an in-house code.

26. Select all Industry Codes that apply and/or fill in the blank if appropriate.

The majority of respondents (34%) use API 1104; 16% use ASME IX, 15% use B31.8, 13% use AWS D1.1. The distribution of code usage is found in Figure 72.

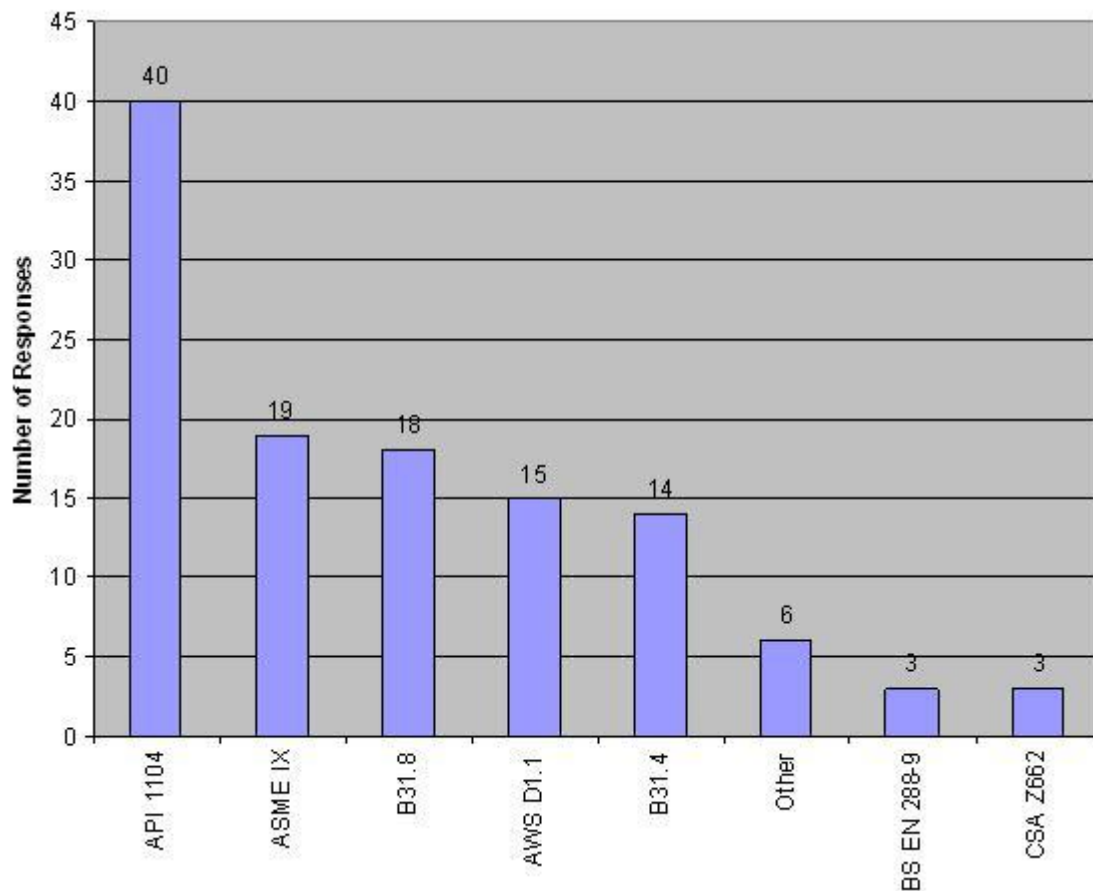


Figure 72: Industry Codes Used to Define Fillet Weld Undercut

Six respondents indicated the use of the following "other" industry codes:

- CSA Z662 03.
- ANST-TC-1A.
- B31.1 and B31.3.
- EEMUA 158.
- DNV OS-F101.
- API 1107 when applicable.

27. Describe acceptable limits for fillet weld undercut according to your In-House code.

Seven respondents provided the following quality criteria from in-house codes:

- For in-service welds (circumferential fillets) undercut shall be removed by grinding the weld toe and blending to remove any stress raisers.
- Follow industry standards but encourage no undercut. Undercut will give a false indication with liquid penetrant or magnetic particle inspection processes.
- Undercut shall be less than 1/64-in. or 12 1/2% whichever is smaller.
- For projects using an alternative acceptance criteria, i.e., CSA Z 662 appendix K, it is generally <1-mm = 10% of pipe circumference.
- Any undercut is unacceptable.
- Workmanship standard.
- Usually slightly stricter than API 1104 or AWS D1.1 depending on the application.

28. Does your company use a NDE method on the OD to inspect for fillet weld reinforcement height?

The majority of respondents (78%) use an NDE method to inspect the OD for fillet weld reinforcement height; 22% do not.

29. What NDE process or processes do you use to inspect for fillet weld reinforcement height?

The vast majority of respondents (93%) use visual inspection to capture fillet weld reinforcement height measurements on the OD of a pipeline; 4% use ultrasonics and 2% use radiography on the ID (Figure 73).

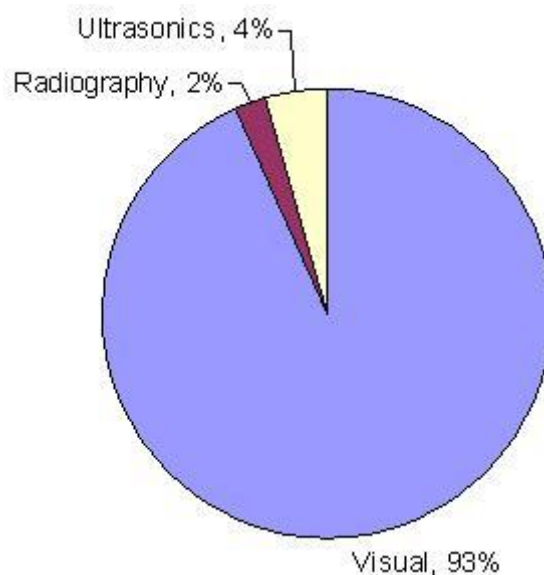


Figure 73: NDE Processes used to Inspect for Fillet Weld Reinforcement Height

30. Which process is the primary NDE process used to measure fillet weld reinforcement height?

Nearly all respondents (95%) use visual inspection as their primary NDE process to inspect fillet weld reinforcement height on the OD of pipelines; 2% use ultrasonics and radiography on the ID (Figure 74).

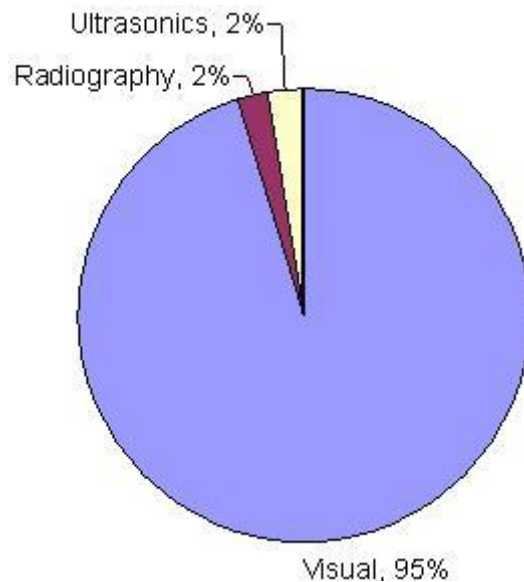


Figure 74: Primary Process used to Inspect for Fillet Weld Reinforcement Height

31. To define acceptable limits for fillet weld reinforcement height, do you use an Industry Code or an In-House Code?

The vast majority of respondents (93%) use an industry code to define acceptable limits for fillet weld reinforcement; 7% use an in-house code.

32. Select all Industry Codes that apply and/or fill in the blank if appropriate.

The majority of respondents (31%) use API 1104, followed by ASME IX (18%), B31.8 (15%), AWS D1.1 (14%) and B31.4 (13%). The distribution of code usage is found in Figure 75.

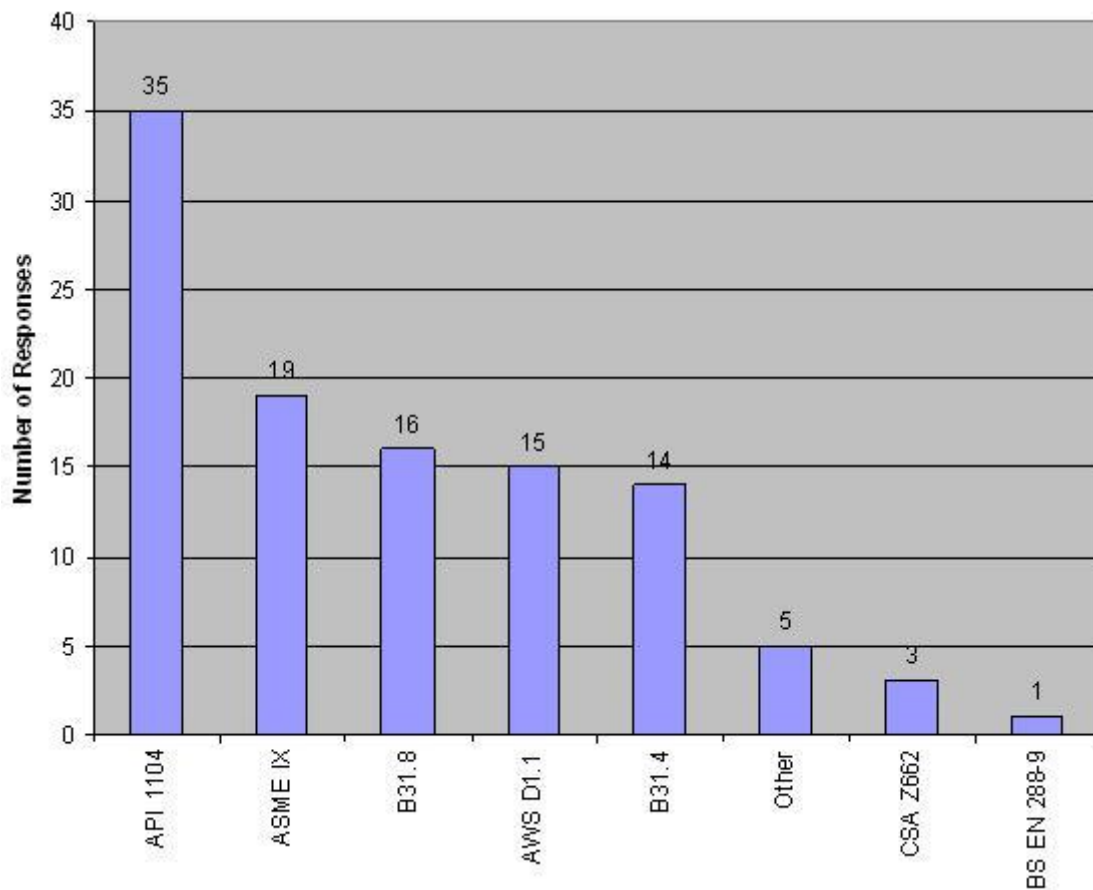


Figure 75: Industry Codes Used to Define Fillet Weld Reinforcement Height

Five respondents indicated that they use the following other codes:

- AS2885.
- In-house visual.
- B31.1 and B31.3 when applicable.
- EEMUA 158.
- B31.3.

33. Describe acceptable limits for fillet weld reinforcement height according to your In-House code.

Three respondents provided the following details about their in-house codes:

- Follow industry standards. Material thickness enters into the height requirement.

- Varies from a two-pass moisture seal to a full fillet weld depending on applications (*i.e.*, Type A sleeve or Type B sleeve).
- Workmanship standard.

34. Does your company use an NDE method to inspect for fillet weld spatter?

Most of the respondents (67%) use an NDE method to inspect for fillet weld spatter; 33% do not.

35. What NDE process or processes do you use to inspect for fillet weld spatter?

The overwhelming majority of respondents (97%) use visual inspection to detect weld spatter on the OD of a pipeline and 3% use radiography for the ID.

36. Which process is the primary NDE process used to measure fillet weld spatter?

100% of respondents indicated that they use visual inspection to measure fillet weld spatter on the OD of a pipeline.

37. To define acceptable limits for fillet weld spatter, do you use an Industry Code or an In-House Code?

The majority of respondents (76%) use an industry code to define acceptable limits for fillet weld spatter; 24% use an in-house code.

38. Select all Industry Codes that apply and/or fill in the blank if appropriate.

The majority of respondents (33%) use API 1104, followed by ASME IX (17%), B31.8 (14%), B31.4 (14%) and AWS D1.1 (10%). The remaining code usage is shown in Figure 76. The six respondents that use other codes did not indicate what other codes.

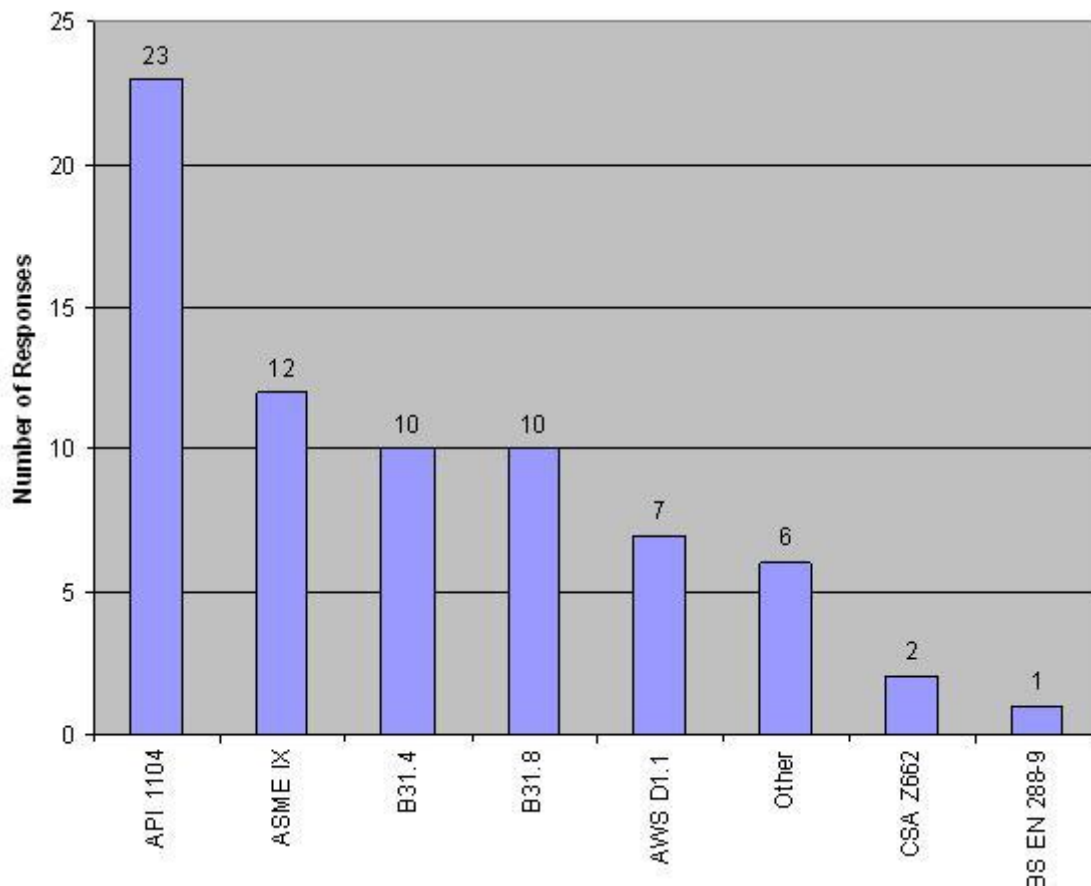


Figure 76: Industry Codes Used to Define Acceptable Fillet Weld Spatter Amounts

39. Describe acceptable limits for fillet weld spatter according to your In-House code.

Nine respondents listed the following details about their in-house acceptance criteria for fillet weld spatter.

- None present.
- Industry standards. In-house requirement is to remove all spatter before inspection and coating.
- None allowed.
- Spatter must be removed.
- Workmanship (see previous).
- Special requirements for weld/base metal cleaning and preparation for subsequent corrosion protection coating applications may be required by specification, code, drawings, etc. Inspector then refers to project/job specific requirements for inspection acceptance criteria.
- All spatter is removed.

- Acceptable if it can be ground out without reducing WT [wall thickness] beyond design limits and no evidence of arc burns. Arc burns are generally cut out.
- None.

40. Does your company use a NDE method to inspect for weld leg size differences?

The majority of respondents (80%) use NDE to inspect for weld leg size differences; 20% do not.

41. What NDE process or processes do you use to inspect for fillet weld leg size differences?

The vast majority of respondents (98%) use visual; 2% use radiography.

42. Which process is the primary NDE process used to measure fillet weld leg size differences?

Again, the vast majority of respondents (98%) use visual; 2% use radiography.

43. To define acceptable limits for fillet weld leg size differences, do you use an Industry Code or an In-House Code?

The majority of respondents (89%) use an industry code to define acceptable limits for fillet weld leg size; 11% do not.

44. Select all Industry Codes that apply and/or fill in the blank if appropriate.

The majority of respondents (30%) use API 1104, followed by ASME IX (17%), B31.8 (16%), AWS D1.1 (15%), and B31.4 (12%). The remaining code usage is shown in Figure 77.

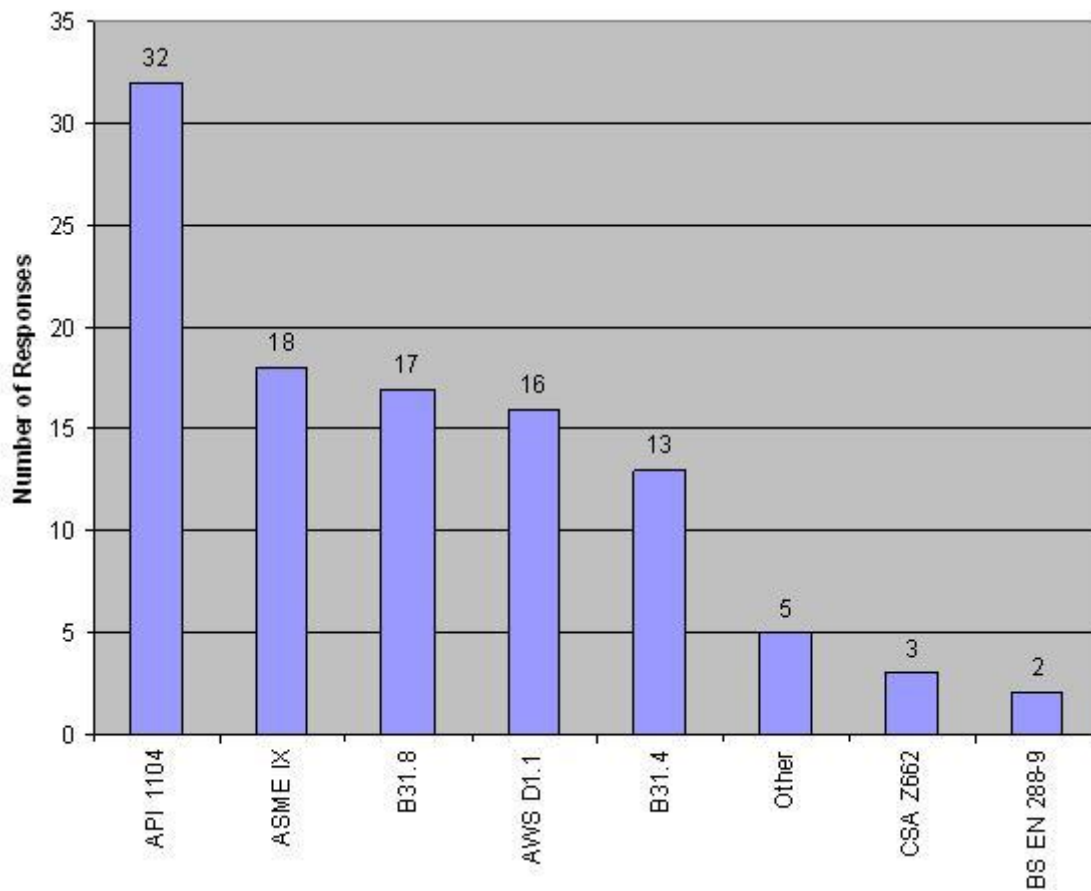


Figure 77: Industry Codes Used to Define Acceptable Fillet Weld Leg Size Differences

Four additional industry codes were identified as being used:

- AS2885
- CSA Z662 03
- EEMUA 158
- API 1107 (when applicable)

One respondent indicated that they comply with the fillet weld leg size requirements found on the design drawings.

45. Describe acceptable limits for fillet weld leg size differences according to your in-house or other code.

Five respondents provided the following description of fillet weld leg size differences:

- Industry standard, company requirement and material thickness dictate.

- Varies with application (*i.e.*, Type A or Type B sleeve).
- Workmanship standard.
- Minimum specified.
- Weld procedures define the weld leg size based on thickness of pipe and sleeve.

6.2 Summary of the Fillet Weld Inspection Criteria

The responses for the fillet weld inspection questions mirrored the response from butt weld inspection questions. The majority of the industry codes used to determine acceptability are the American welding codes (API and ASME). Visual inspection appears to be the dominant inspection method which can be attributed to the joint configuration not being very receptive to other forms of NDE (e.g. radiography and ultrasonic) due to the wall thickness variations. Also, this weld type does not penetrate the full thickness of the pipe wall so there is no need to inspect the ID surface of the pipe, the only weld discontinuities of interest in the survey would be present on the OD surface of the pipe.

46. What coating system(s) does your company use?

The respondents that selected "coating" in question 1 were taken directly to question 46. The responses to this question exhibited some commonality as shown in Figure 78.

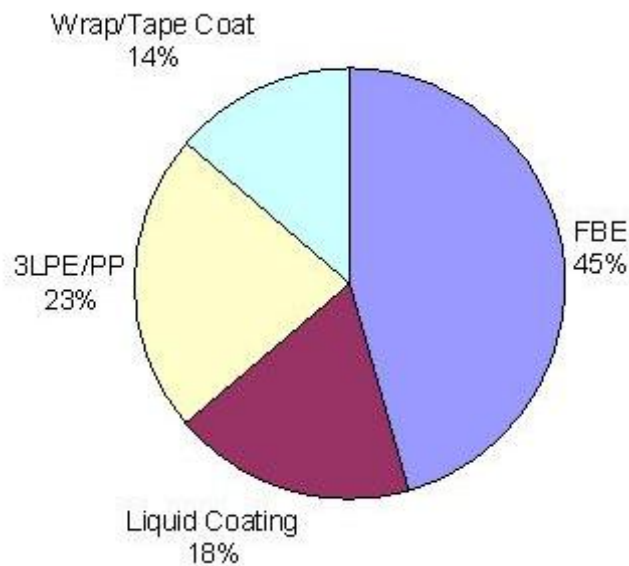


Figure 78: Coatings System Used by Survey Respondents

Individual responses are listed below as bullet points.

Company A. FBE, 3LPE, 3LPP.

Company B. Coal Tar Enamel, FBE, Three Layer Coatings, Tape Coat.

Company C.	FBE, Powercrete, Powercrete J, Protal 7200.
Company D.	Specialty Polymer Coatings is a formulator and manufacturer of 100% solids liquids coatings for pipeline applications ranging in service temperature up to 304F. Our materials are used for new construction and rehabilitation. We also manufacture coating materials designed for application to blasted but damp pipe surface.
Company E.	Extruded Polyethylene, Extruded Polypropylene, Pritec, Powercrete.
Company F.	Fusion Bonded Epoxy and Liquid Epoxy Coating systems for new construction.
Company G.	For new construction we prefer Mil-applied Scotchkote 6233 FBE or Mil-applied Napgard 2500 series FBE.
Company H.	Fusion Bond Epoxy, Three layer PE, and PP.
Company I.	FBE.
Company J.	STOPAQ CZ Wrap and Paste.
Company K.	Most new pipe installed is fusion bond epoxy with two part epoxy for the girth welds. Some of the pipe has an abrasion resistant coating over the fusion bond epoxy for bores. The brands we use are 3M or DuPont for the fusion bond epoxy. The abrasion resistant coatings we use are either 3M, Dupont, or Powercrete. The two part epoxies we use for girth welds and re-coats are Protal 7200, Powercrete J, Devgrip 238, and wax tape.
Company L.	Fusion Bond Epoxy, Tape coatings, Pritec, Coal Tar, Somastic Wax.
Company M.	Fusion Bonded Epoxy (FBE) and 2 layer FBE; 3 layer polyobfine (PO) liquids (epoxies).

47. What is the expected Design Life of the coating system(s)?

The responses to this question exhibited some commonality as shown in Figure 79.

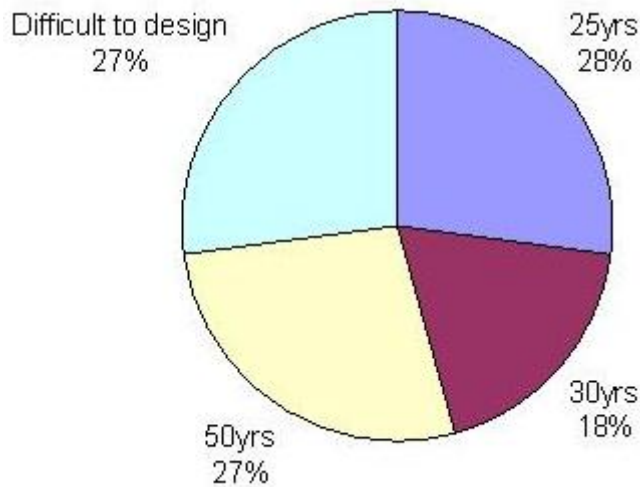


Figure 79: Expected Design Life of Coating Systems

Individual responses are listed below as bullet points.

- Company A. 25 years typically.
- Company B. 20 - 30 years.
- Company C. 30 years.
- Company D. Our design life in the formulation is based on a 50 year design life.
- Company E. 50 years.
- Company F. Dependent upon environment.
- Company G. Understanding that the design life of a coating system is directly proportional to the surface preparation it is reasonable to achieve 30 to 40 years service life.
- Company H. 50 years.
- Company I. 25 hrs.
- Company J. Unlimited life time if stored properly.
- Company K. As long as possible.
- Company L. According to manufacturer's specifications.
- Company M. It is difficult to design, too many factors are involved, you wish it lasted forever.

48. What is the expected Service Life of the coating system(s)?

The responses to this question exhibited some commonality as seen in Figure 80.

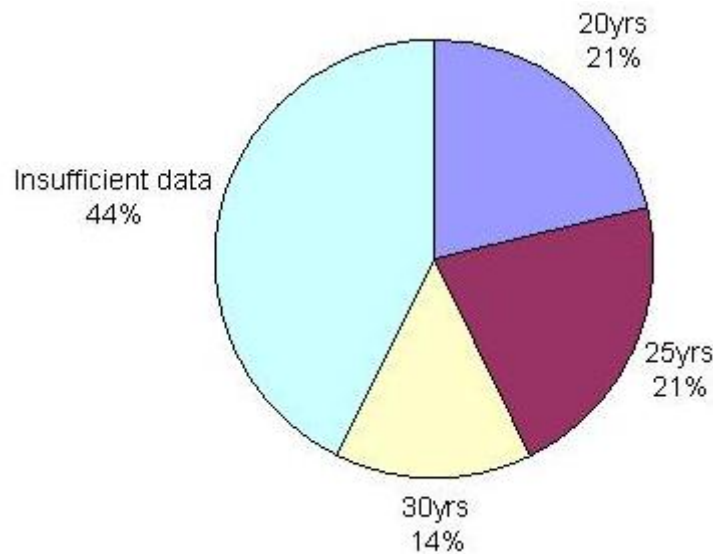


Figure 80: Expected Service Life of Coating Systems

Individual responses are listed below as bullet points.

- Company A. 25 years typically.
- Company B. 20 to 30 years.
- Company C. 20 years.
- Company D. Specialty Polymer Coatings has urethanes with 25+ years in-service. We have epoxies, epoxy/urethanes and novolacs with over 15 years in-service history.
- Company E. We have not reached it.
- Company F. Dependent upon environment.
- Company G. We have had some of these thin film epoxies in service over 20 years.
- Company H. More than 30 years to date.
- Company I. 25.
- Company J. Greater than 30 years.
- Company K. We use methods of above ground survey techniques to determine where we might have coating problems and corrosion problems before re-coating a section. Therefore, we don't have a set service life, but instead try to monitor.
- Company L. Generally used as long as there is no evidence of failure.
- Company M. It is difficult to design, too many factors are involved, you wish it lasted forever.
- Company N. Insert discussion/interpretation of survey results here along with any conclusions that can be drawn from this question.

49. Has your company experienced pipeline coating failures?

85% of the respondents indicated that they have experience pipeline coating failures; 15% have not.

50. What types of failures have you experienced for each coating system used?

Table 18 is a summary of the coatings failures experienced by the respondents.

Table 18: Summary of Coating System Failures Experienced by Respondents

Coating System	Failures Experienced
All	Cathodic disbondment, adhesion
Coal Tar Enamel	On line travel coating too fast of line travel and lack of cleanliness of pipe before application of coating.
FBE	Excessive jeeping due to pin holes in coating from the yare coating deterioration due to soil conditions Three Layer Coatings Tape Coat
All	Blistering, disbondment
2 part liquid epoxies	The failures have been related to off-ratio material being applied to the pipe. This has occurred only in rehabilitation utilizing spray application.
Coal tar	degradation Powercrete disbondment
Poly-Backed Tapes and Heat Shrink Sleeve	Coating failures associated mostly with historical coatings not in use with new construction or rehab projects today. Those include poly-backed tapes and heat shrink sleeve disbondment.
Asphalt Coatings	Disbondment
Older Tape Systems and Heat Shrinks	Older tape system and heat shrinks at girth welds have occurred causing shielding. Degradation of coal tar enamels has been evident on older systems, some over 50 years.
All	Mechanical damage
Applied Asphalt, Somatic, Etc.	We haven't experienced many failures from the new coatings. The older coatings in our system, hot applied asphalt, somatic, etc. do have problems with disbonding, cracking, etc.
Pritec, coal tar, and tape coatings	Disbondment
FBE	Blisters, cracks, delamination
3 layer PE/PP	Cohesive failure between layers

51. Does your company use an Industry code or an In-House code to define surface preparation procedures?

The majority of respondents (85%) use industry codes to define surface preparation procedures; 15% use in-house codes.

52. Circle all Industry Codes that apply and/or fill in the blank if appropriate

Of the eleven respondents that answered this question, 73% indicated that they use industry codes other than the ones that appeared in the survey list. Of the codes on the survey list, 36% of respondents use RP0402; 27% use RP0602, RP0303 and RP0375; 18% use API5L and RP0178; and 9% use API 1104 (see Figure 81).

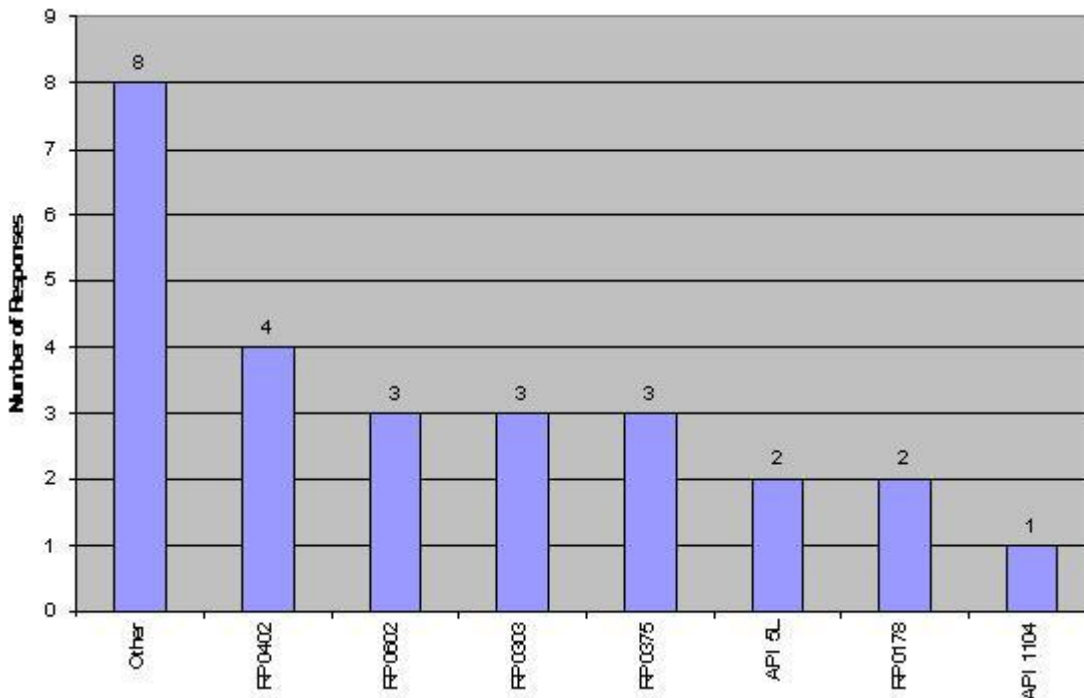


Figure 81: Industry Codes used to Define Surface Preparation Prior to Coating

Eight respondents indicated that they use the following "other" industry codes:

- SSPC Surface Preparation Standards (SSPC-SP6 specifically mentioned once)
- CSA Standards
- ISO
- ISO/API
- NACE #2 Near White Blast
- NACE No. 3
- NACE RPO394 (2 respondents use this code)
- NACE RPO490

- NACE RPO188
- NACE RPO287
- NACE RPO375
- NACE RPO274
- Minimum ST 2

The next set of questions (53 to 56) asked the respondent to describe their in-house surface preparation procedures.

53. Describe pipe weld and surrounding surface cleaning requirements (*e.g.*, cleaning weld spatter, removing imperfections, etc.)

Two respondents listed the following requirements:

- Remove all slag and weld spatter. Sand blast to SSPC SP 10 or NACE #2 requirements.
- We specify SSPC-SP 11 to be followed to clean up the weld and weld spatter.

54. Describe your weld surface finish requirements.

Two respondents listed the following surface finish requirements.

- Power wire brush. Remove all slag and dingle berries.
- We specify SSPC-SP 11 to be followed to clean up the weld and weld spatter.

55. Describe the blast profile requirements for your grit blasting procedure.

Two respondents described the following blast profile requirements.

- SSPC SP 10 or NACE #2 requirements.
- Sand, grit, or copper slag are the only blast medias allowed. We then specify SSPC-SP 10 so the steel is blasted to a near-white finish. We require a 2-4 mil anchor profile.

56. Describe any additional surface preparation procedures.

Two respondents provided the additional surface preparation details.

- Preheat in winter.
- We have a few in-house procedures for coating application, and I only briefly summarized what was asked above.

57. What pipe materials grades do you use?

Sixty-four people responded to this question: 88% use X52; 81% use X60; 78% use both X42 and X65; 72% use Grade B; 64% use X70; 50% use X46; and 45% use X56. The remaining pipe grade usage is shown in Figure 82.

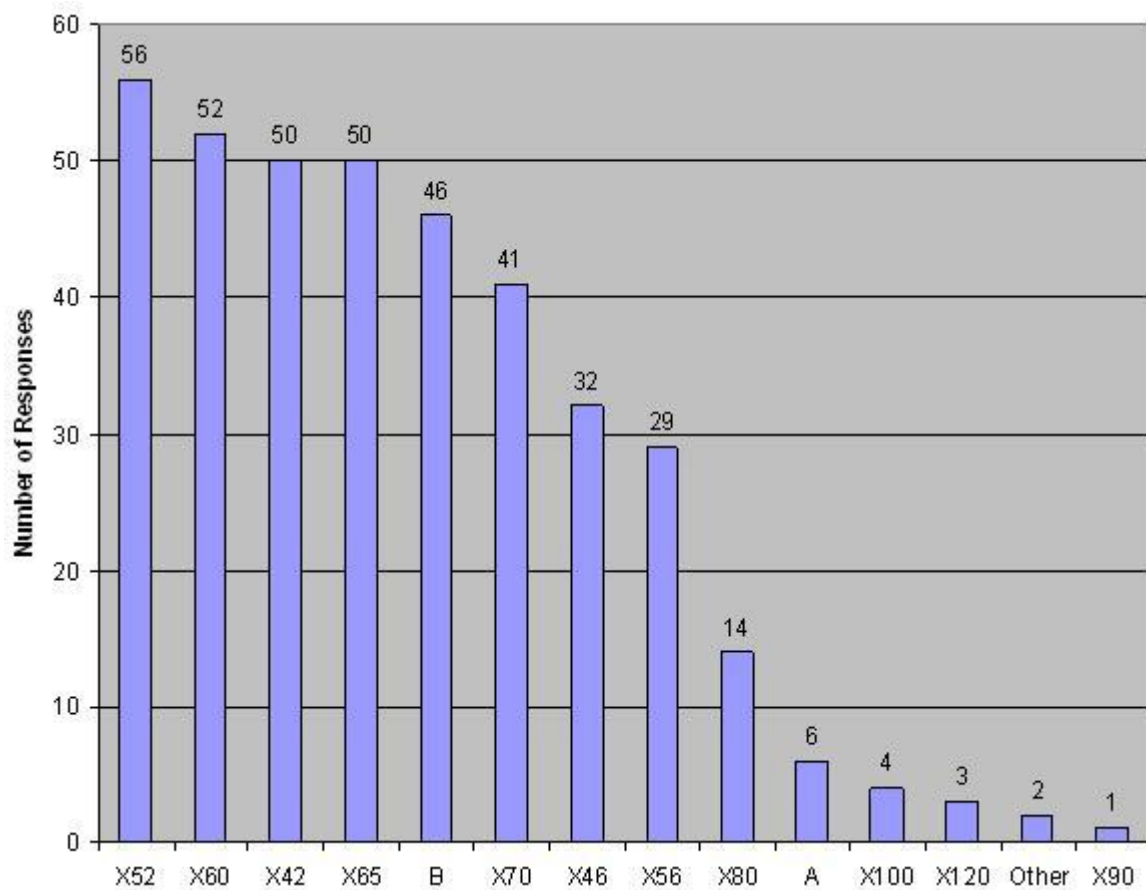


Figure 82: Material Grades used by Respondents

Two respondents indicated that they use the following "other" material grades:

- ASTM A312TP321.
- ASTM A333GR 6 (LT50).
- ASTM A333 GR3 (LT150) - seamless.
- ASTM A790 GR S32760 - welded.
- BS 3602 GR410 seamless - hot finish.
- ASTM A106 GRB.
- ASTM A155 GR C45.
- Duplex.
- Superduplex.
- Increasing amounts of 825, 625, or 316 Lined/Clad Pipes.

58. What range of pipe diameters and wall thicknesses do you use?

Sixty respondents provided input to this question. The pipe diameters used by each respondent are shown in Figure 83; they range from 0.50-in. to 64-in. On the small end of the spectrum, the median OD pipe size is 2-in. On the large end of the spectrum the median OD pipe size is 42-in. The average pipe OD is 22-in.

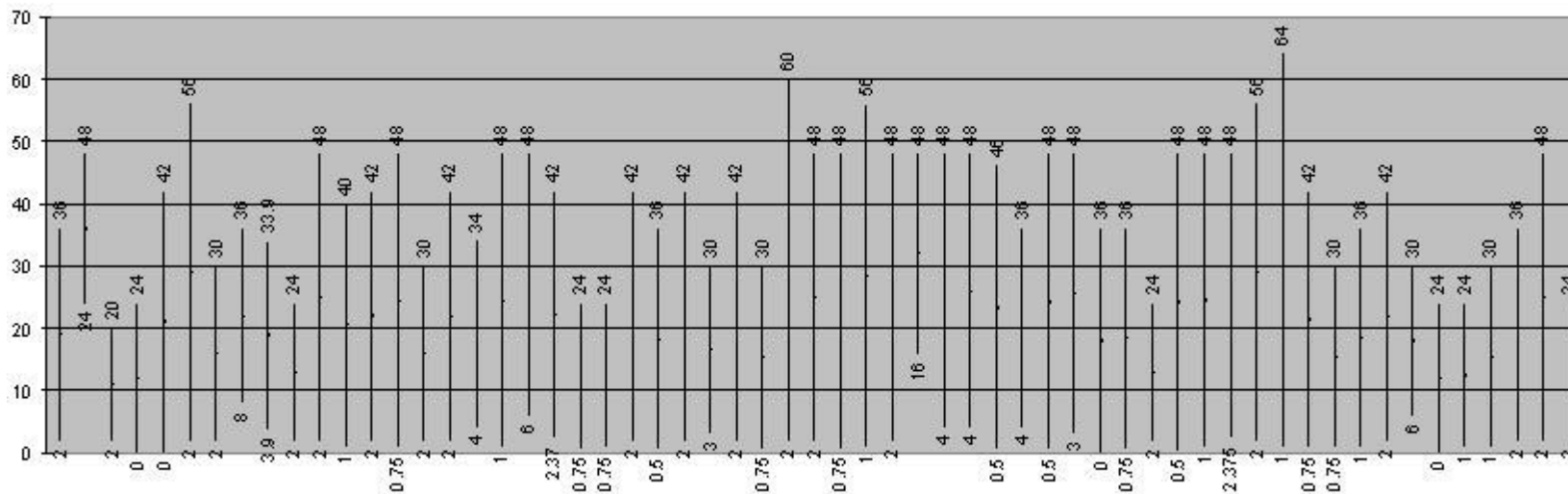


Figure 83: Pipe Diameter Ranges Used by Respondents

Thirty-nine respondents provided information regarding the wall thicknesses. The wall thicknesses used by each respondent is shown in Figure 84; they range from 0.12- to 2-in. On the small end of the spectrum, the median minimum wall thickness is 0.156-in. On the large end of the spectrum, the median maximum wall thickness is 42-in. The average wall thickness is 0.56-in.

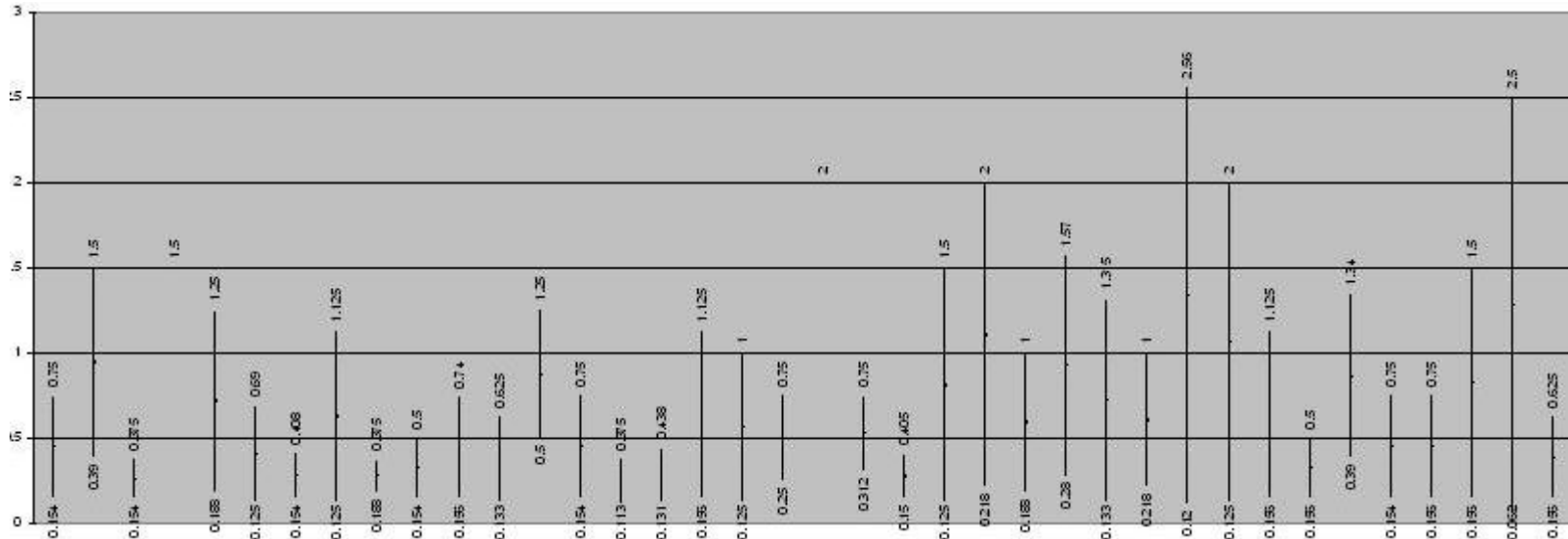


Figure 84: Wall Thickness Ranges Used by Respondents

59. Has your company attempted to define a coordination protocol between welding contractors and coating applicators?

70% of respondents have not attempted to define a coordination protocol between welding and coating contractors; 30% have.

60. What types of problems did you encounter?

Seventeen respondents listed the following types of problems encountered while trying to establish a protocol between welding and coating contractors:

- Coating material specifications. Application specifications.
- My company does both the welding and the coating.
- The condition of completed weld surface and adjacent area.
- Coating applicators need more surface prep that welders perform (clean/buff spatter, dress grind repairs, clean weld toes).
- Cut back issues related to automatic welding.
- Timing, weather, location, schedule.
- Communication and training.
- Have not defined period of time for cooling and subsequent hydrogen diffusion prior to coating.
- Competence, knowledge of coating application, past experience/practices, poor specs.
- Generally the prime contractor is providing both welding and coating.
- Being a pipeline welding contractor we are often hiring in coating contractors for field joint applications. In other cases the operator has hired them in. The largest issues from a welding contractor standpoint is that the coating processes tend to take a good deal of space and may hold up the line on occasions. With respect to weld joint quality, our welds are often governed by overriding client specifications that take into account the limitations of field joint coating. In addition, most welds are cleaned up for visual inspection and finally AUT which requires at the least a smooth surface for scanning. We don't however take part in the scale removal through blasting.
- This portion of project handled by Gas Operations and Engineering. I support welding operations.
- We were able to work both together by getting them both on board before the work started.
- The usual; welds not cleaned or too rough for the coating system, welds meet minimum code requirements.
- We assign full responsibility to a general contractor for both welding and coating.

- Finding a contractor capable of performing the welding and coating to satisfaction. We prefer to work with one contract.

61. What is the most important issue you need to resolve between welding contractors and coating applicators?

Twelve respondents identified the following issues as the most important to resolve between welding contractors and coating applicators:

- Application specifications.
- What is an acceptable surface condition for the coating applicators.
- Surface prep.
- Timing when outside influences may not allow for welds to sit for sufficient time prior to coating.
- Communication.
- Have not defined period of time for cooling and subsequent hydrogen diffusion prior to coating.
- Specification and coating inspection.
- Generally the prime contractor is providing both welding and coating.
- Schedule.
- Who is responsible to prepare the surface to be coated.
- Workmanship of weld.

62. Are there any additional topics that should have been addressed by this survey?

Twelve respondents offered the following additional topics of interest that were not addressed as part of this survey:

- The option for "both" welding and coating should be asked as the first question. Pipeline operators would typically be involved in both, as well as, mainline contractors.
- Test program for qualification used (*e.g.*, API 1104 App B, etc.).
- Field joint materials, who applies field joint system.
- Weld repairs (grinds and rewelds).
- Method of preparation before coating. Any temperature limitations.
- Fillet weld inspection; dry versus wet.

- What are the training methods employed by the contractor or manufacturer to ensure qualification of the applicators of coating materials in the field? As welders are required to demonstrate capabilities to perform under specific requirements, so should the coating application personnel.
- Type of company answering (I work for a design contractor). Whether working in onshore or offshore, pipeline or structural arenas. Weld reinforcement height is only part of the story. Reinforcement shape will be significant.
- Survey should recognize, especially for cross-country type pipeline work that the welding and coating responsibilities are typically let to the same contractor.
- Timing between welding and coating. To address out-gassing.
- We actually control both welding and coating but survey forced a pick of either / or but not both.
- The survey could have been broken down by pipe material type.

63. What types of recommendations would you like to see as a result of this survey?

Fifteen respondents proposed the following suggested types of recommendations that should result from this survey:

- Recommended interaction for Field applied FBE as opposed to sleeves or two-part epoxy.
- Field joint applicators qualification.
- Best practices for inspection of welds and welds coatings.
- Industry Data.
- Recommendation on time lapse between weld completion and coating.
- Coordination strategies, application guidelines, etc.
- Lessons Learned to be shared.
- Protocols for field welding and coating.
- Basic protocols between weld finish time and coating time.
- Details of survey results.
- Clear guidelines for different coating systems. In my area (offshore pipelines) they are not clearly defined.
- Please keep me informed on recommended coordination of welding and coating processes.
- Recommendation that both functions be overseen by a coordinating organization.
- How to reduce, eliminate, or at least determine an acceptable degree of weld spatter.

- Improved materials and coating application procedures for use by pipeline operating companies for use in maintenance and construction.

64. Do you have any additional comments?

Seven respondents provided the following additional comments:

- We have experienced localized coating holidays as a result of high cap and spatter, especially on field applied FBE joints (thin film).
- Consideration of timing should be given to welding, inspection and coating of welds when time constraints have an influence versus waiting. A good example would be directional drill pull backs, working in roadways and areas that may flood.
- We would offer our assistance to the completion of this important effort for our industry.
- This is actually a fairly substantial problem in the procurement of pipe or coated pipe for pipelines. If one buys uncoated pipes and then sends it to a coater, lots of disputes and claims for bad surface come back to Purchaser. Only by purchasing coated pipes can the Purchaser stay out of surface quality dispute.
- I will be interested to see the results of this study.
- I do not fully understand the purpose of this survey.
- I would not want to change our welding practices or procedures. I would rather have improved coatings for use with existing weld procedures.

65. Are you interested in providing additional input for this program?

Twenty-five respondents indicated that they are interested in providing additional input for this program.

6.3 Conclusions

Since the majority of the survey recipients were American based pipeline operator and pipeline companies, the responses to the butt welding (or production) and fillet welding (modification or repair) questions were in line with expectations: API 1104 is used for field welding of both liquid and gas transmission pipelines; ASME B31.8 is used for construction of gas transmission pipelines; and ASME B31.4 is used for construction of liquid transmission pipelines. Both B31.8 and B31.4 refer to ASME Section IX for welding procedure and welder qualification.

Visual inspection was the main NDE method used to determine the presence and the amount of undercut, reinforcement and weld spatter for butt welds. Visual inspection is a good technique to inspect and measure weld discontinuities on the outside diameter (OD) of the pipe but it may not be applicable to inspecting the inside diameter (ID) surface of the pipe. The typical nondestructive evaluation (NDE) methods used to find volumetric imperfections and discontinuities on the ID surface of the pipe is ultrasonic or radiographic inspection. These inspection techniques have difficulty determining the extent of surface discontinuities since the magnitude of these discontinuities are small relative to the thickness being inspected. For this reason, surface discontinuities (e.g. undercut, excessive bead height) are typically measured manually for acceptance if the surface is accessible.

It is important to note that the NDE required is directly affected by the design of the pipeline. If the design of the pipeline is a strain-based design then there are tighter tolerances for imperfections that need to be met. This type of design lends to ultrasonic or radiographic inspection. Less critical/ low pressure pipeline designs may only require a visual inspection during welding to assure proper weld quality. For this same reason, many of the acceptance criteria is slightly more strict than typical industry codes.

For fillet welding applications, visual inspection appears to be the dominant inspection method, which can be attributed to the joint configuration not being very applicable to other forms of NDE (e.g. radiography and ultrasonic), due to wall thickness variations. Also, this weld type does not penetrate the full thickness of the pipe wall so there is no need to inspect the ID surface of the pipe, the only weld discontinuities of interest in the survey are present on the OD surface of the pipe.

The primary reasons for coating failures include lack of coordination between the welding, preparation, and coating steps, including improper or inadequate surface preparation of the weld zone, or coating application procedures not designed to work with the specified weld features. At the present time, interactions between pipeline welding contractors and applicators of field applied pipe coatings are minimal at best. The pipeline industry lacks comprehensive field testing procedures for welding and coating of steel pipeline joints, hot taps, or other maintenance items.

Appendix C: Simulated Girth Weld Testing Procedures

7.1 *Sample Prep and Coating:*

1. Grit blast with 16 grit AlO₂
2. Verify correct surface profile by using a replicate tape and save tape in lab notebook
3. Coat weld with 2-part epoxy
 - a. Making sure no sign of flash rust is present and resurface as necessary
 - b. Verify thickness that is being applied with wet thickness gauge
 - c. Cure for a minimum of 24 hours
 - d. Measure dry thickness and record, ASTM D-4138
 - e. Perform low voltage holiday detector to verify continuity of coating, ASTM G-62

7.2 *Weld undercut sample preparation*

1. Expose the ends
 - a. Cut the ends off the coated sample using a abrasive cut-off wheel
 - b. Taking care to expose the weld and undercut areas, avoiding edge effects
 - c. Photograph the edges for later reference, with microscope
 - d. Visually inspect the wetting of the undercut for qualitative reference
 - e. Measure and record the thickness of the coating on the weld, at the weld's edge, and the stock material, utilizing microscope image
2. Prep for accelerated corrosion testing
 - a. Mask exposed side of weld area with tape
 - b. Cover remaining exposed steel with protective coating, zinc and epoxy
3. Perform accelerated corrosion test, ASTM B-117
 - a. Utilize a cyclic salt fog spray, Japanese criteria CCT-1
 - b. Monitor corrosion in the samples

7.3 *Cap Height Test Samples*

1. Measure thickness
 - a. Cut the ends off the coated sample using a abrasive cut-off wheel
 - b. Taking care to expose the weld and undercut areas, avoiding edge effects
 - c. Photograph the edges for later reference, with microscope
 - d. Visually inspect the wetting for qualitative reference
 - e. Measure and record the thickness of the coating on the weld, at the weld's edge, and the stock material, utilizing microscope image
2. Perform impacts
 - a. Place coated sample in impact tester and verify the weld cap is directly under the tip of the tup
 - b. Perform impacts in center area of weld an inch from the ends, allowing for two impacts
 - c. Impact will be from yet to be determined inches above tip of weld cap
 - i. This value corresponds to the drop to cause coating failure in the weld with the lowest cap height of .075 in.
 - d. Photograph the impacted area for comparison later
3. Prep for accelerated corrosion testing
 - a. Cover remaining exposed steel with protective coating, zinc and epoxy
4. Perform accelerated corrosion test, ASTM B-117
 - a. Utilize a cyclic salt fog spray, Japanese criteria CCT-1
 - b. Monitor corrosion in the samples

7.4 Quantify Corrosion

1. Photograph results
 - a. Take photos and microscope images for comparisons and analysis
 - b. Follow ASTM D 610 for visual evaluating corrosion
2. Undercut tests
 - a. Take note of how much corrosion has proceeded under the coating from the edge following the under cut
 - b. Using visual aids classify the amount the corrosion has followed the undercut and any corrosion in the area of the impacts
3. Cap height tests
 - a. Using visual aids classify the amount of corrosion resulting around the impacted area

Appendix D: Simulated Girth Welds – Data

8.1 Simulated Girth Welds – Cross-section Images

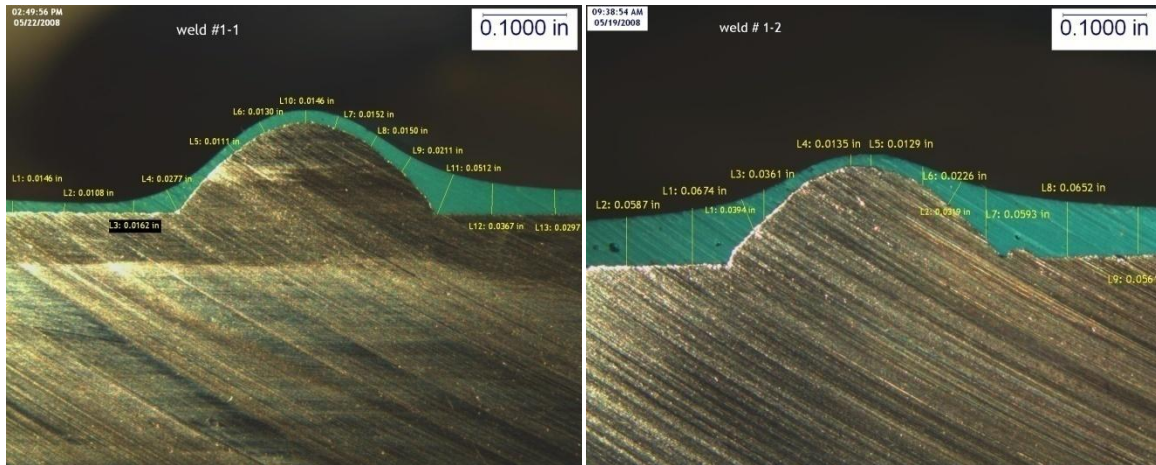


Figure 85: Sample weld 1 Cross section

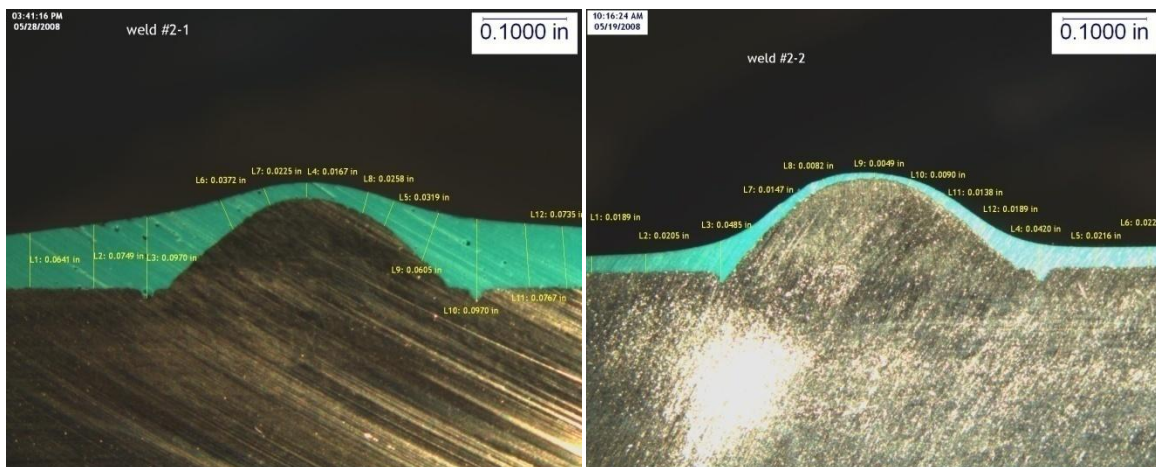


Figure 86: Sample weld 2 cross section

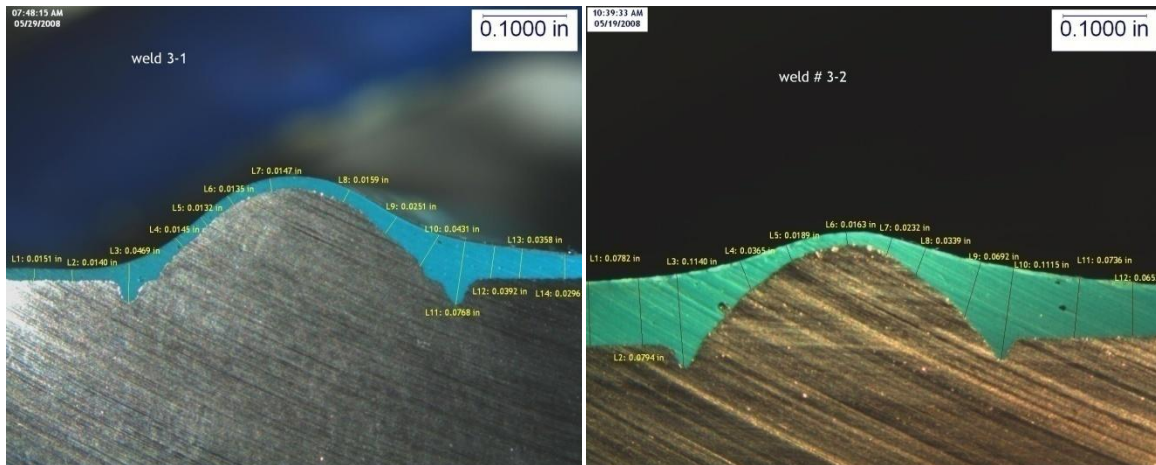


Figure 87: Sample weld 3 cross section

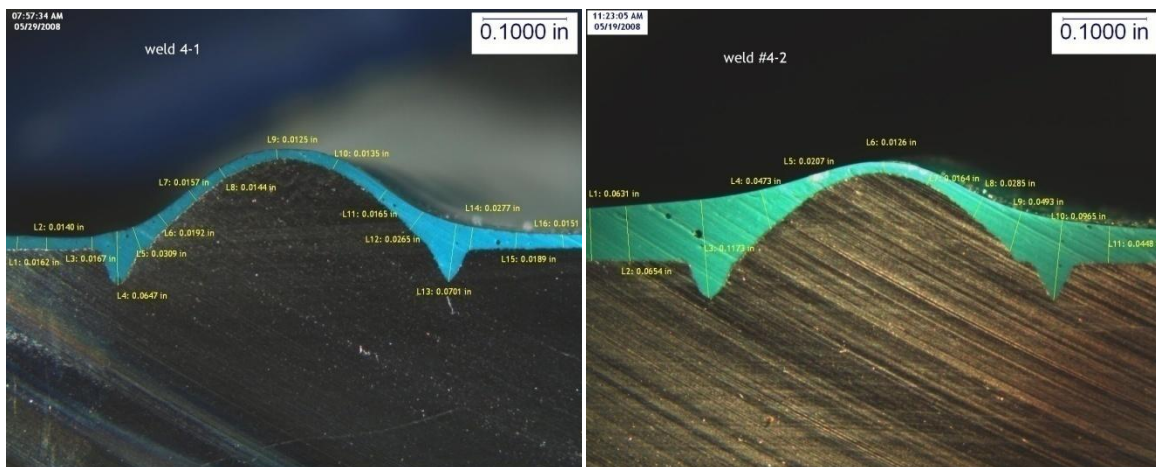


Figure 88: Sample weld 4 cross section

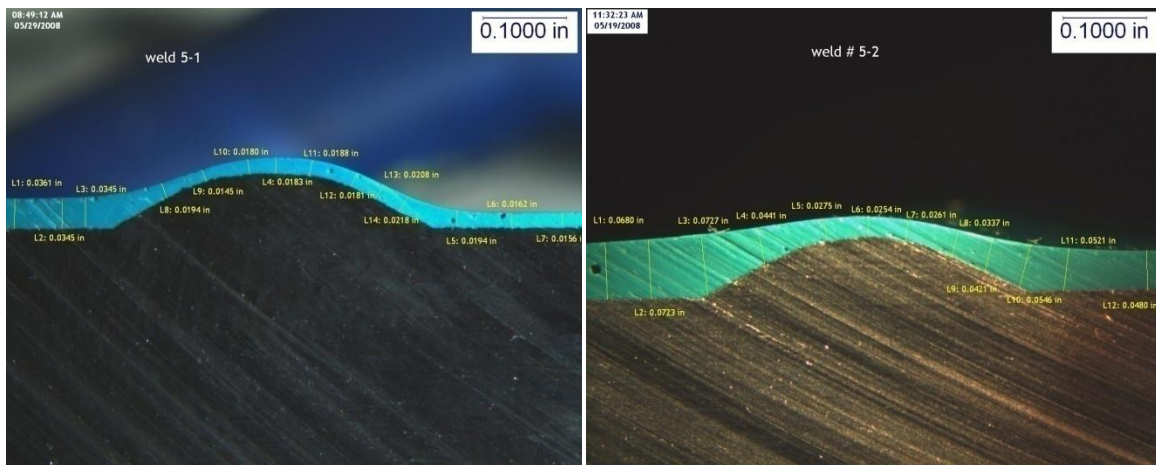


Figure 89: Sample weld 5 cross section

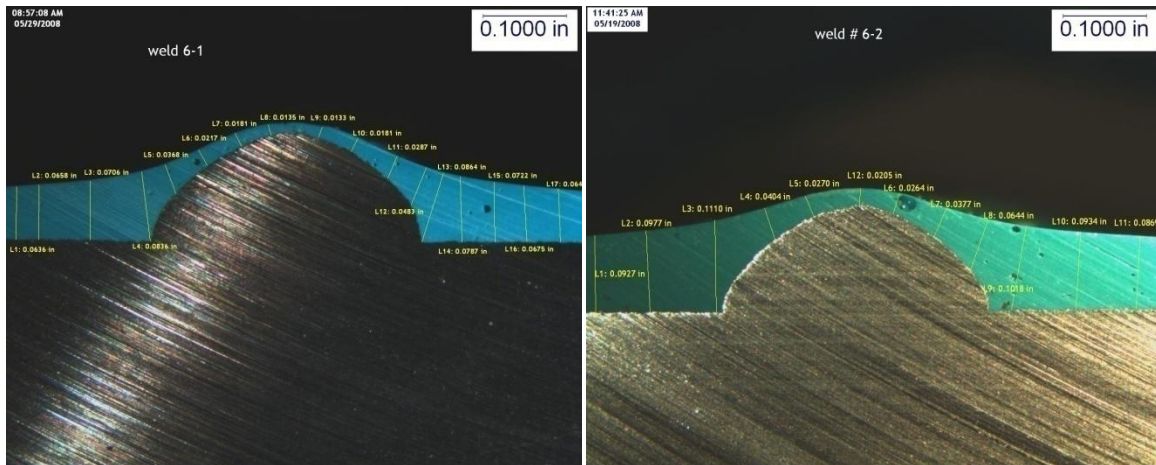


Figure 90: Sample weld 6 cross section

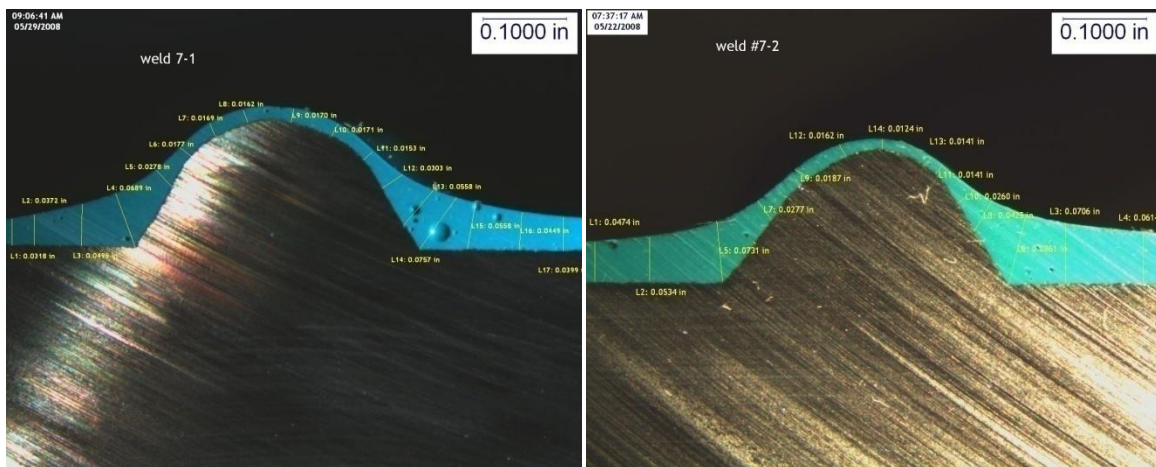


Figure 91: Sample weld 7 cross section

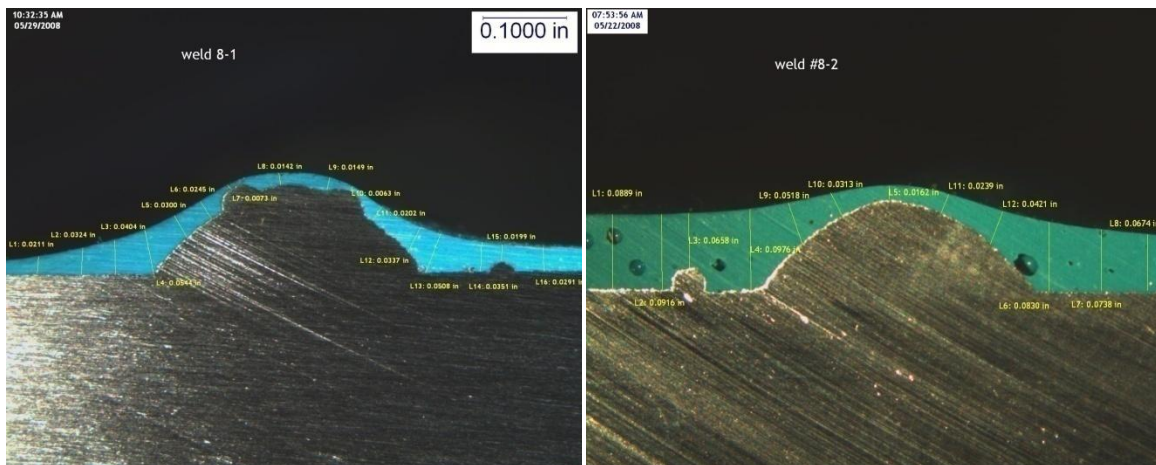


Figure 92: Sample weld 8 cross section

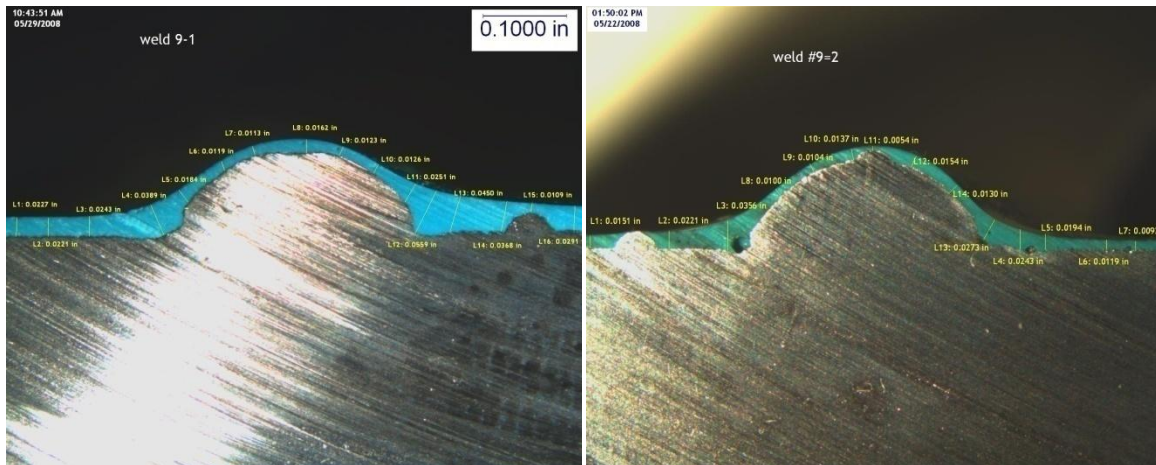


Figure 93: Sample weld 9 cross section

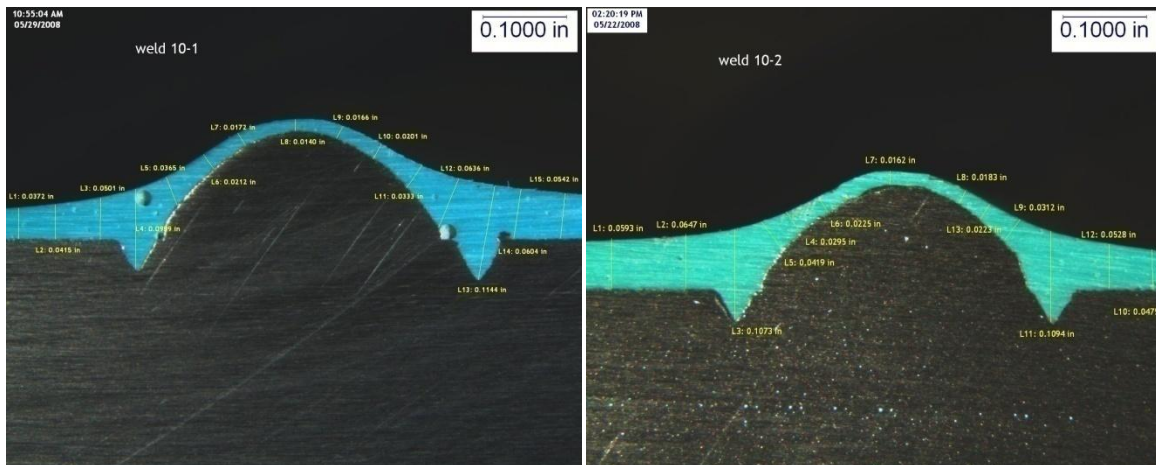


Figure 94: Sample weld 10 cross section

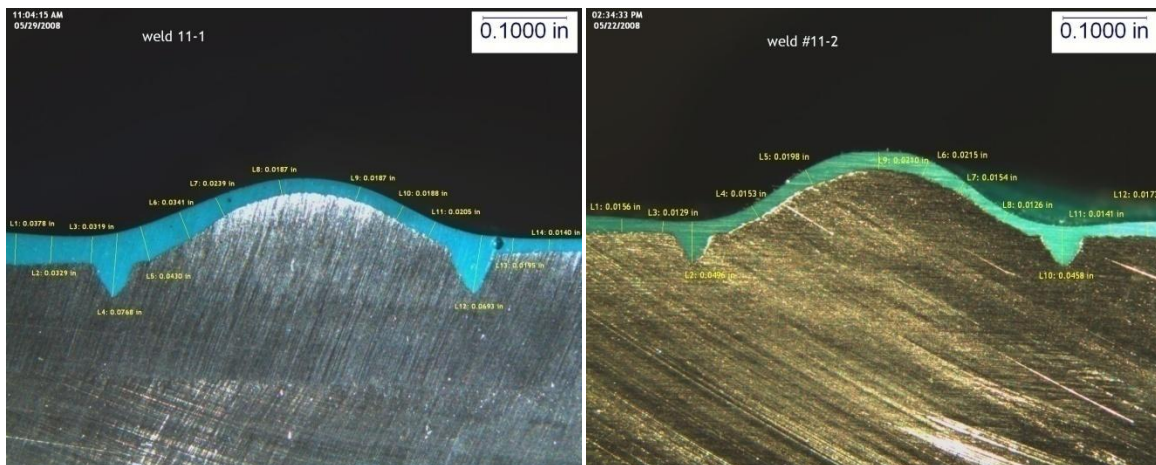


Figure 95: Sample weld 11 cross section

8.2 Simulated Girth Welds – Accelerated Testing Result Images



Figure 96: Simulate girth weld 1-1, after salt fog exposure



Figure 97: Simulate girth weld 1-1, after picking

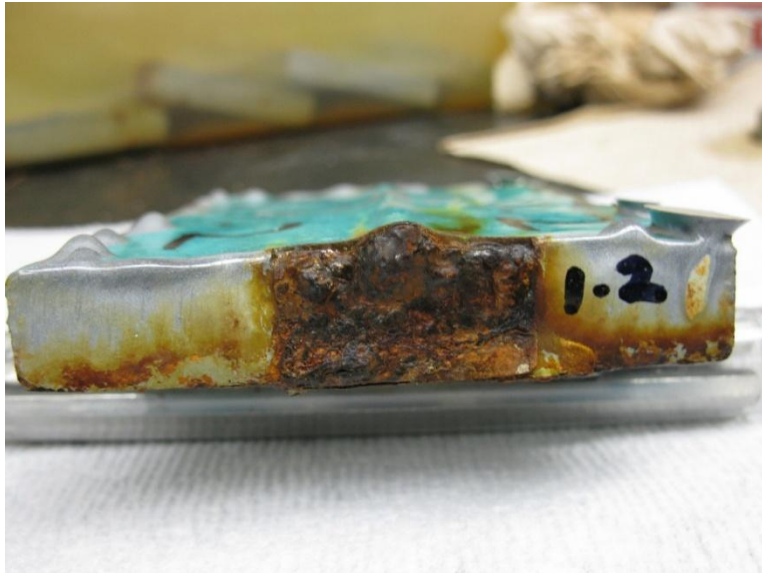


Figure 98: Simulate girth weld 1-2, after salt fog exposure

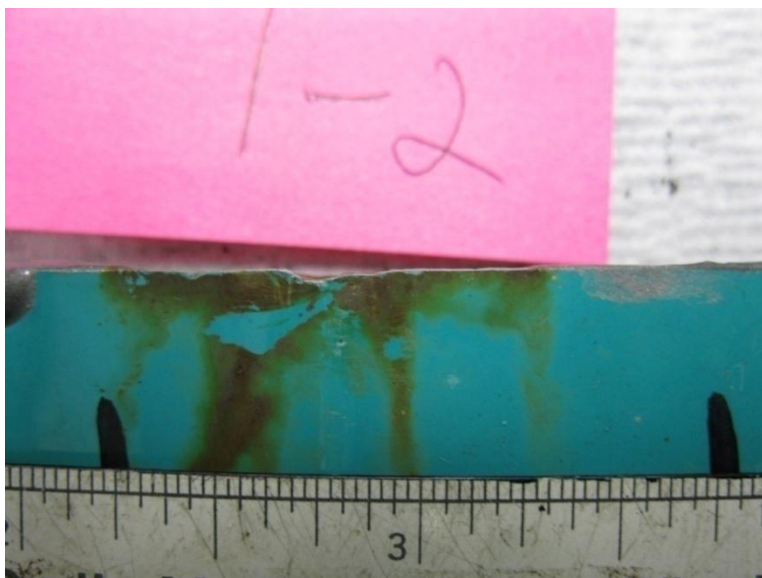


Figure 99: Simulate girth weld 1-2, after picking



Figure 100: Simulate girth weld 2-1, after salt fog exposure



Figure 101: Simulate girth weld 2-1, after picking



Figure 102: Simulate girth weld 2-2, after salt fog exposure

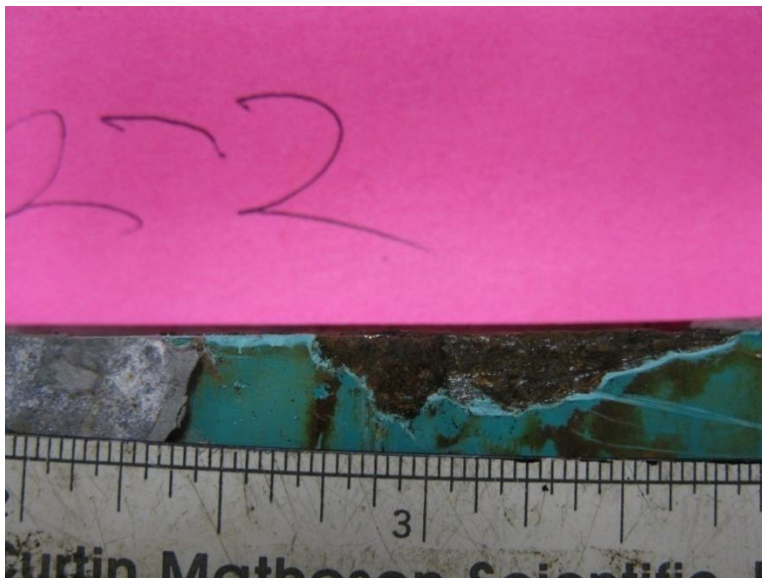


Figure 103: Simulate girth weld 2-2, after picking



Figure 104: Simulate girth weld 3-1, after salt fog exposure

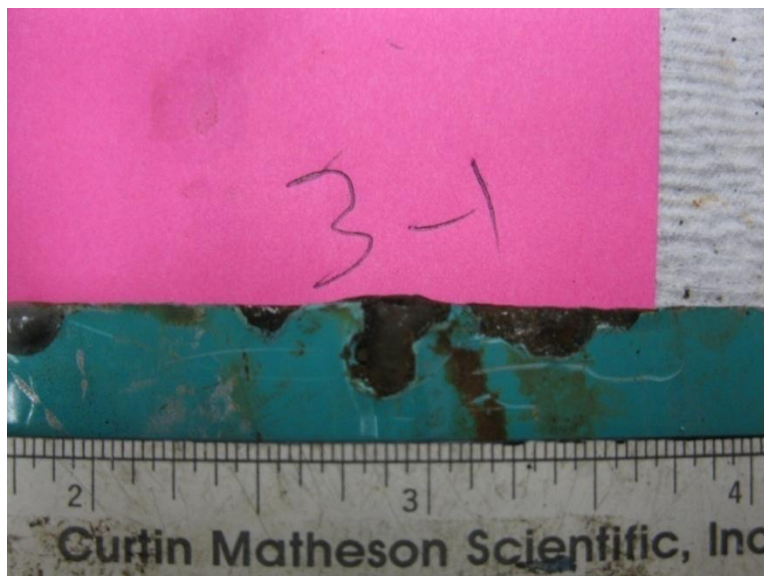


Figure 105: Simulate girth weld 3-1, after picking



Figure 106: Simulate girth weld 3-2, after salt fog exposure

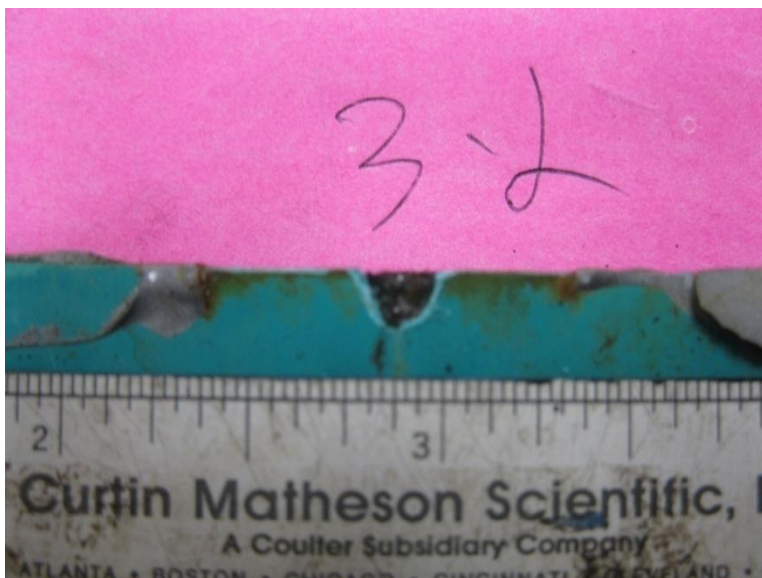


Figure 107: Simulate girth weld 3-2, after picking



Figure 108: Simulate girth weld 4-1, after salt fog exposure

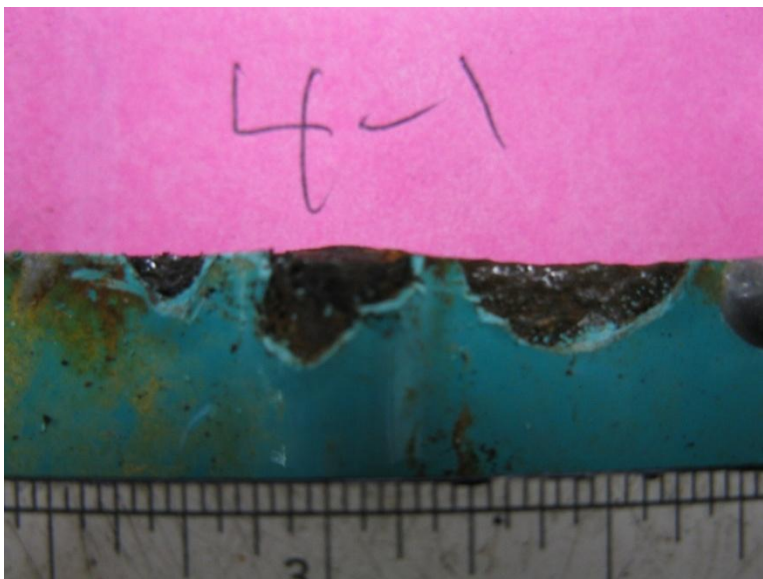


Figure 109: Simulate girth weld 4-1, after picking



Figure 110: Simulate girth weld 4-2, after salt fog exposure



Figure 111: Simulate girth weld 4-2, after picking

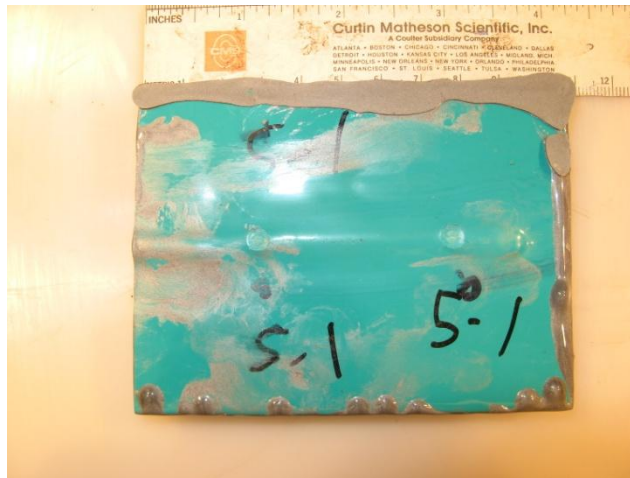


Figure 112: Sample 5-1 after impacts and before accelerated corrosion testing



Figure 113: Simulate girth weld 5-1, after salt fog exposure

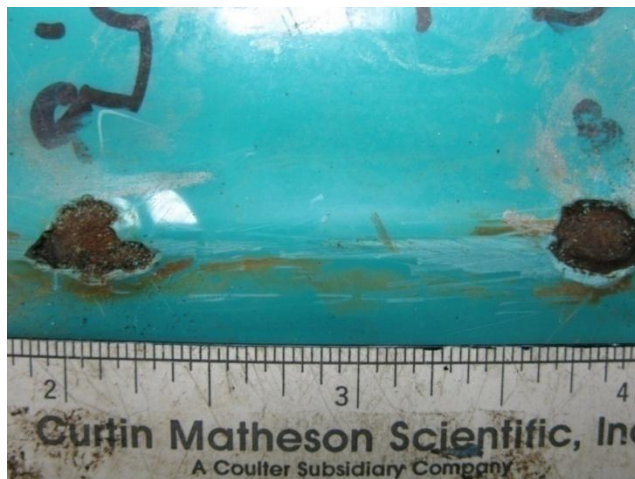


Figure 114: Simulate girth weld 5-1, after picking



Figure 115: Sample 5-2 after impacts and before accelerated corrosion testing



Figure 116: Simulate girth weld 5-2, after salt fog exposure



Figure 117: Simulate girth weld 5-2, after picking



Figure 118: Sample 6-1 after impacts and before accelerated corrosion testing



Figure 119: Simulate girth weld 6-1, after salt fog exposure



Figure 120: Simulate girth weld 6-1, after picking



Figure 121: Sample 6-2 after impacts and before accelerated corrosion testing



Figure 122: Simulate girth weld 6-2, after salt fog exposure



Figure 123: Simulate girth weld 6-2, after picking



Figure 124: Sample 7-1 after impacts and before accelerated corrosion testing



Figure 125: Simulate girth weld 7-1, after salt fog exposure



Figure 126: Simulate girth weld 7-1, after picking



Figure 127: Sample 7-2 after impacts and before accelerated corrosion testing

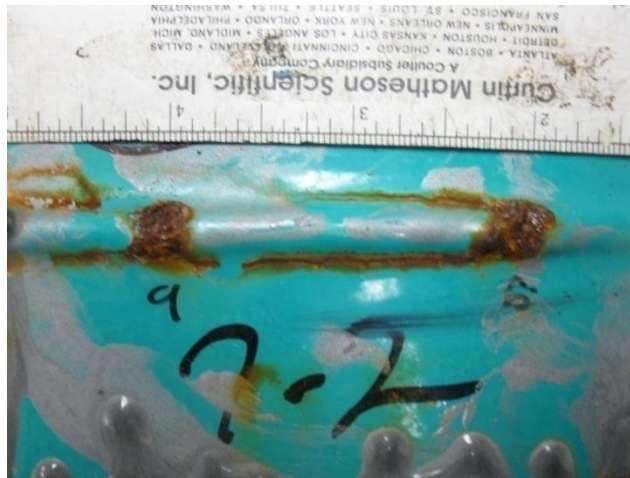


Figure 128: Simulate girth weld 7-2, after salt fog exposure



Figure 129: Simulate girth weld 7-2, after picking



Figure 130: Sample 8-1 after impacts and before accelerated corrosion testing



Figure 131: Simulate girth weld 8-1, after salt fog exposure



Figure 132: Simulate girth weld 8-1, after picking

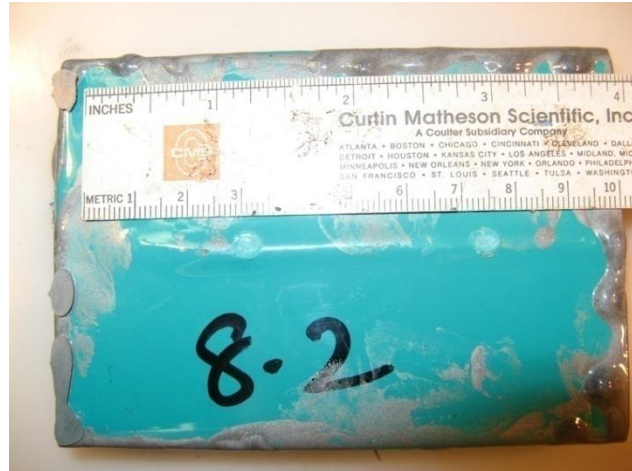


Figure 133: Sample 8-2 after impacts and before accelerated corrosion testing



Figure 134: Simulate girth weld 8-2, after salt fog exposure



Figure 135: Simulate girth weld 8-2, after picking

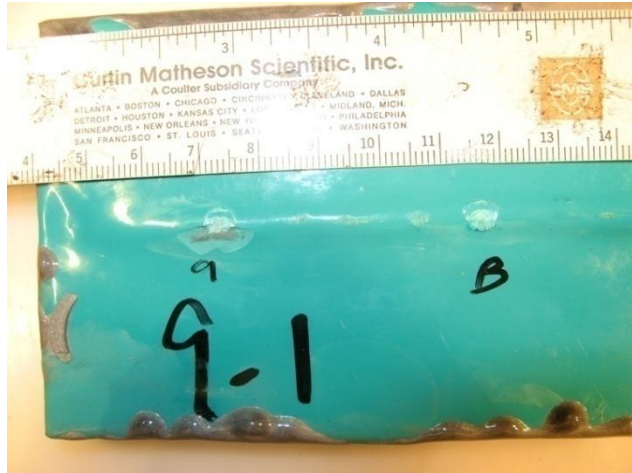


Figure 136: Sample 9-1 after impacts and before accelerated corrosion testing



Figure 137: Simulate girth weld 9-1, after salt fog exposure



Figure 138: Simulate girth weld 9-1, after picking

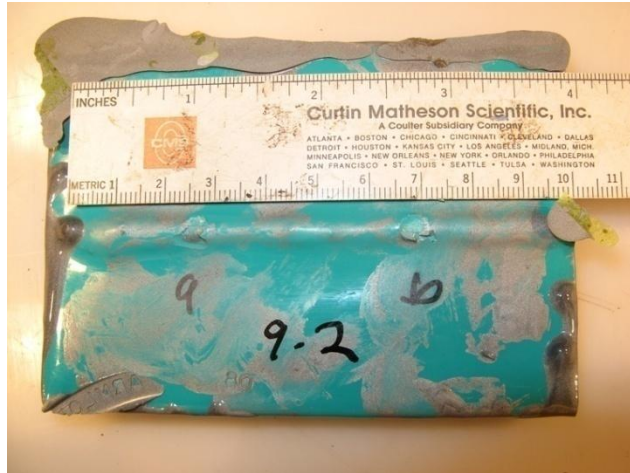


Figure 139: Sample 9-2 after impacts and before accelerated corrosion testing



Figure 140: Simulate girth weld 9-2, after salt fog exposure



Figure 141: Simulate girth weld 9-2, after picking



Figure 142: Sample 10-1 after impacts and before accelerated corrosion testing



Figure 143: Simulate girth weld 10-1, after salt fog exposure



Figure 144: Simulate girth weld 10-1, after picking

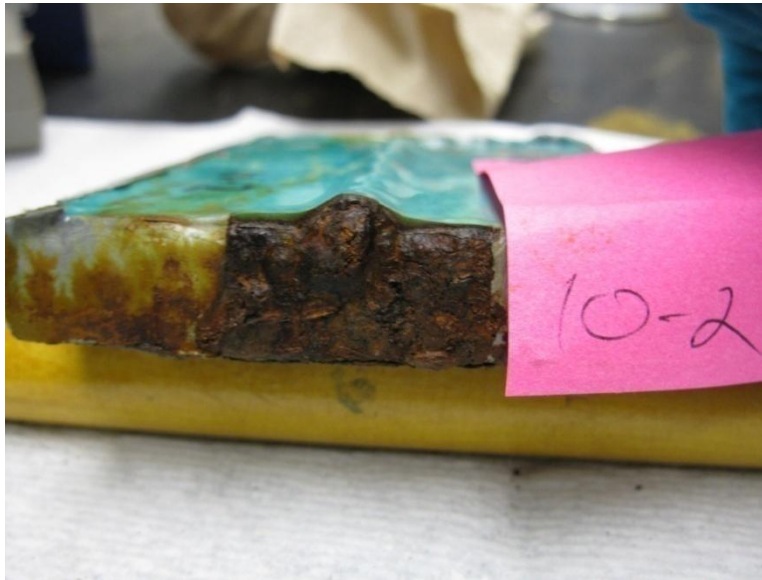


Figure 145: Simulate girth weld 10-2, after salt fog exposure

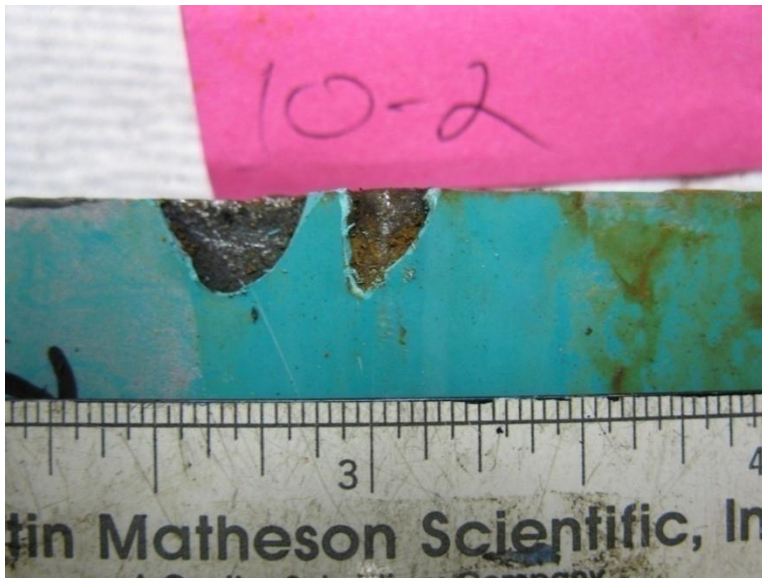


Figure 146: Simulate girth weld 10-2, after picking



Figure 147: Sample 11-1 after impacts and before accelerated corrosion testing



Figure 148: Simulate girth weld 11-1, after salt fog exposure



Figure 149: Simulate girth weld 11-1, after picking

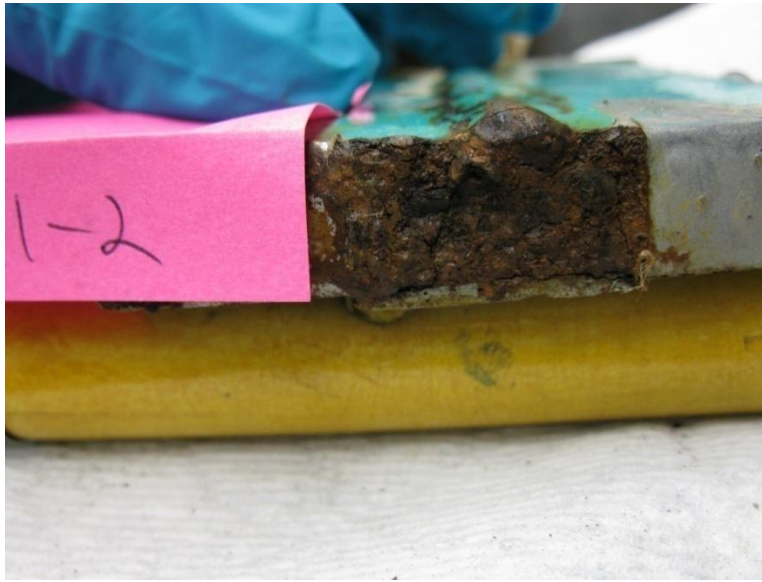


Figure 150: Simulate girth weld 11-2, after salt fog exposure

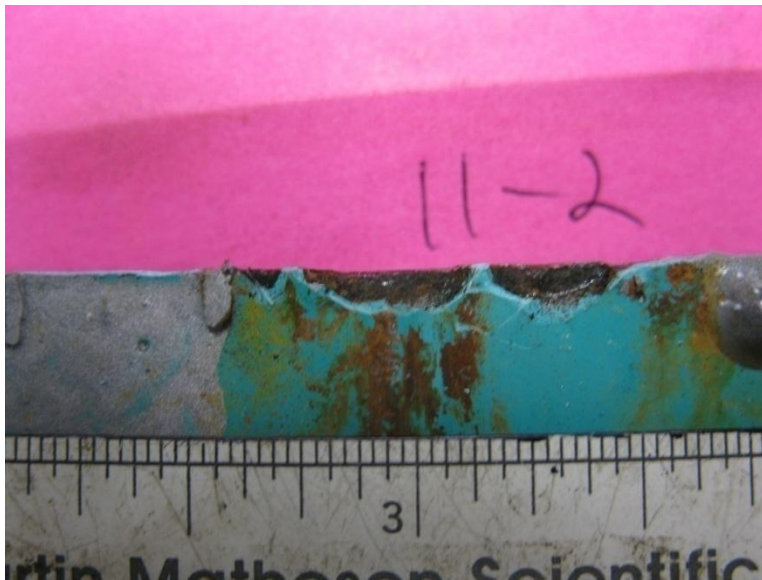


Figure 151: Simulate girth weld 11-2, after picking


Appendix E: In-Field Weld – Data

9.1 Pre-coating Conditions Report

Table 19: The test results and application conditions for each of the test pieces

Piece/Test Type	Salt Content	Anchor Profile	Dew Point	Ambient Temp	Application Temp	Avg. Coating Thickness	Application Date
6 inch FBE 2 hr.	0.7 µg/cm ²	3.8 mils	64°F	95°F	463°F	22 mils	27-May
6 inch 2 part 2 hr.	4.0 µg/cm ²	2.9 mils	64°F	97°F	ambient	28 mils wet	27-May
24 inch FBE 2 hr.	2.8 µg/cm ²	3.4 mils	66°F	95°F	463°F	27 mils	27-May
24 inch FBE 5 hr.	3.9 µg/cm ²	3.5 mils	70°F	81°F	463°	20 mils	28-May
6 inch FBE 5 hr.	6.1 µg/cm ²	3.0 mils	69°F	89°F	463°F	18 mils	28-May
6 inch 2 part 5 hr.	3.9 µg/cm ²	3.3 mils	69°F	89°F	ambient	30 mils wet	28-May
24 inch 2 part 5hr.	too low to register	2.9 mils	68°F	89°F	ambient	35 mils wet	28-May
24 inch 2hr. 2part	0.7 µg/cm ²	3.1 mils	70°F	85.5°F	ambient	40 mils wet	28-May
6 inch Preheat 2 part	too low to register	2.4 mils	70°F	85.5°F	ambient	40 mils wet	28-May
6 inch FBE preheat	2.1 µg/cm ²	3.0 mils	70°F	85.5°F	463°F	22 mils	28-May
24 inch FBE Preheat	2.2 µg/cm ²	3.3 mils	70.5°F	78°F	463°F	24 mils	29-May
6 inch FBE other electrode	3.3 µg/cm ²	3.4 mils	67°F	86.5°F	463°F	16 mils	29-May
6 inch 2 hr sleeve	1.9 µg/cm ²	2.5 mils	67°F	86.5°F	ambient	40mils wet	29-May
6 inch 5hr sleeve	5.6 µg/cm ²	3.3 mils	66°F	88°F	ambient	35mils wet	29-May
24 inch Preheat 2part	3.8 µg/cm ²	3.8 mils	66°F	88°F	ambient	40mils wet	29-May

9.2 CRC-Evans Procedure Qualification Record



This information is the proprietary property of CRC-Evans Automatic Welding which contains trade secrets and/or know how and may only be used in conjunction with equipment rented from CRC-Evans Automatic Welding.

PROCEDURE QUALIFICATION RECORD

Project: EWI Coating Applications

Weld No: N/A

Material Grade: API 5L X-70

Material Mfr. / Ht No.: N/A

Diameter: 24"

Wall Thickness: 0.515"

Date Weld Completed: 04/05/08

CW Side Welded By: Ryan

Page 1 of 2

Electrode Trade Name: TS-6

Electrode Manufacturer: Thyssen

Electrode Class.: ER70S-G

Shielding Gas (%): See Shielding Below

Electrical Current/Polarity: DCEP

Position: 5G

CCW Side Welded By: Mike Maine

Pass No.	Backweld	Hot	Fill 1	Fill 2	Fill 3	Cap		
Travel Direction	Downhill	Downhill	Downhill	Downhill	Downhill	Downhill		
Electrode Diameter	0.9 mm TS-6 Ht# 509126	0.9 mm TS-6 Ht# 509126	0.9 mm TS-6 Ht# 509126	0.9 mm TS-6 Ht# 509126	0.9 mm TS-6 Ht# 509126	0.9 mm TS-6 Ht# 509126		
Gas Flow Rate (CFH)	100	100	70	70	70	70		
Shielding Gas Type (%)	75Ar / 25CO ₂	100 CO ₂	85Ar / 15CO ₂	85Ar / 15CO ₂	85Ar / 15CO ₂	85Ar / 15CO ₂		
C.T.W.D (mm)	0.125" - 0.375"	0.250" - 0.625"	0.375" - 1.125"	0.375" - 1.125"	0.375" - 1.125"	0.375" - 1.125"		
Oscillation Rate (BPM)	Not Applicable	Not Applicable	150-200	150-200	150-200	150-200		
Oscillation Width (mm)	Not Applicable	Not Applicable	As Required	As Required	As Required	As Required		
Head Angle	0° to 7° Lead	0° to 7° Lead	0° to 7° Lead	0° to 7° Lead	0° to 7° Lead	0° to 7° Lead		
Equipment Type & Process	IWM GMAW	P260 GMAW	P260 PGMAW	P260 PGMAW	P260 PGMAW	P260 PGMAW		

Figure 152: CRC-Evans Welding Procedure

9.3 Cross-section of In-field Welds – Images

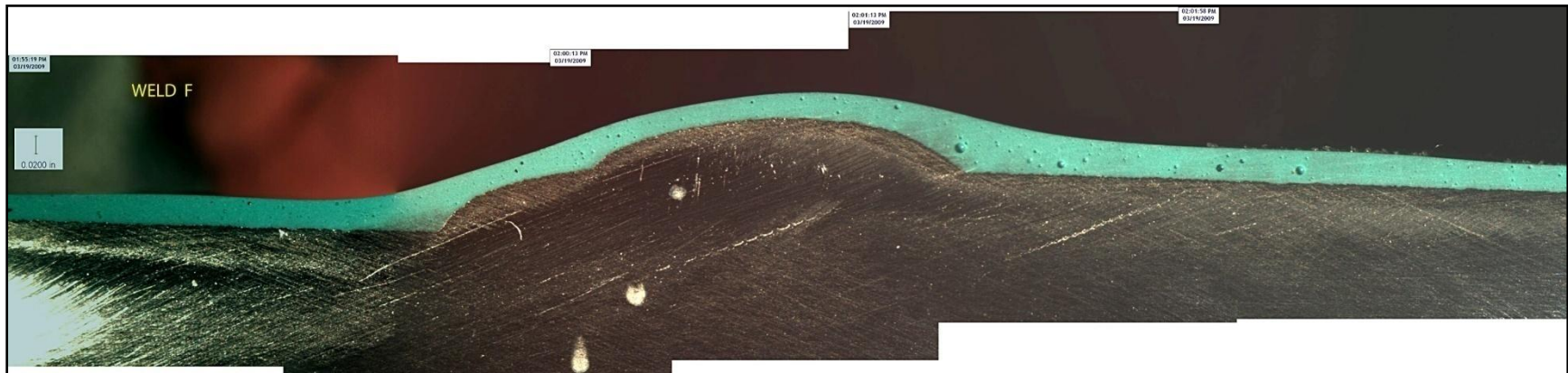


Figure 153: Cross-section image of the welded area of 2 -part epoxy coating applied after 2 hour hold

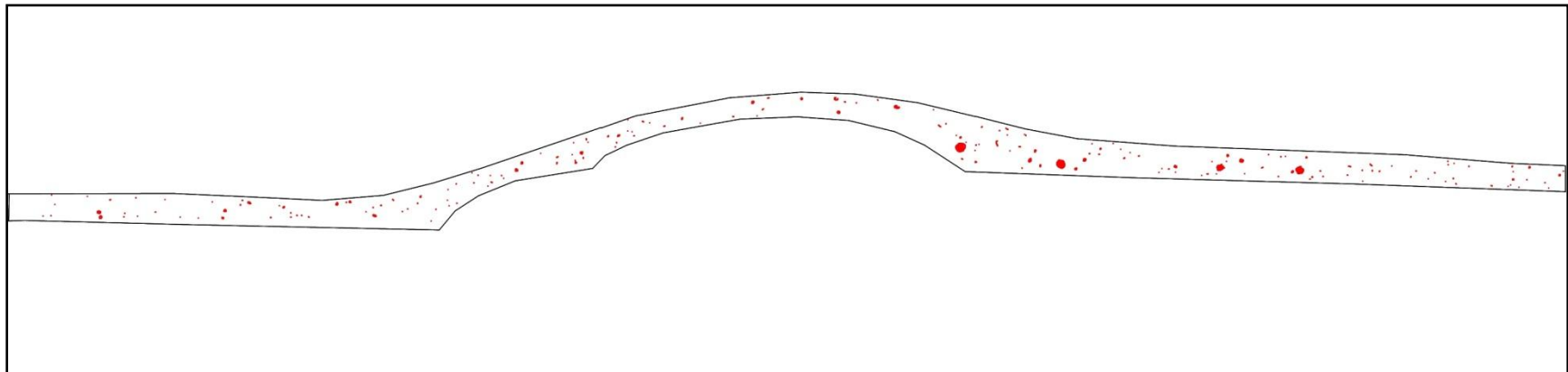


Figure 154: Schematic showing the coating area and the voids/bubbles in red of 2-part epoxy coating applied after 2 hour hold

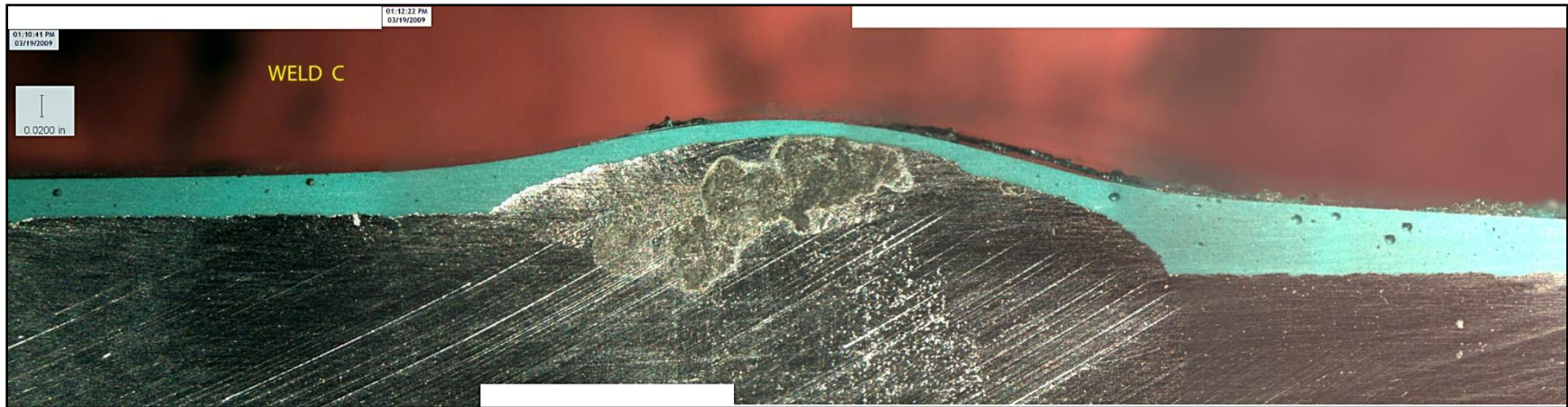


Figure 155: Cross-section image of the welded area of 2-part epoxy coating applied after 5 hour hold

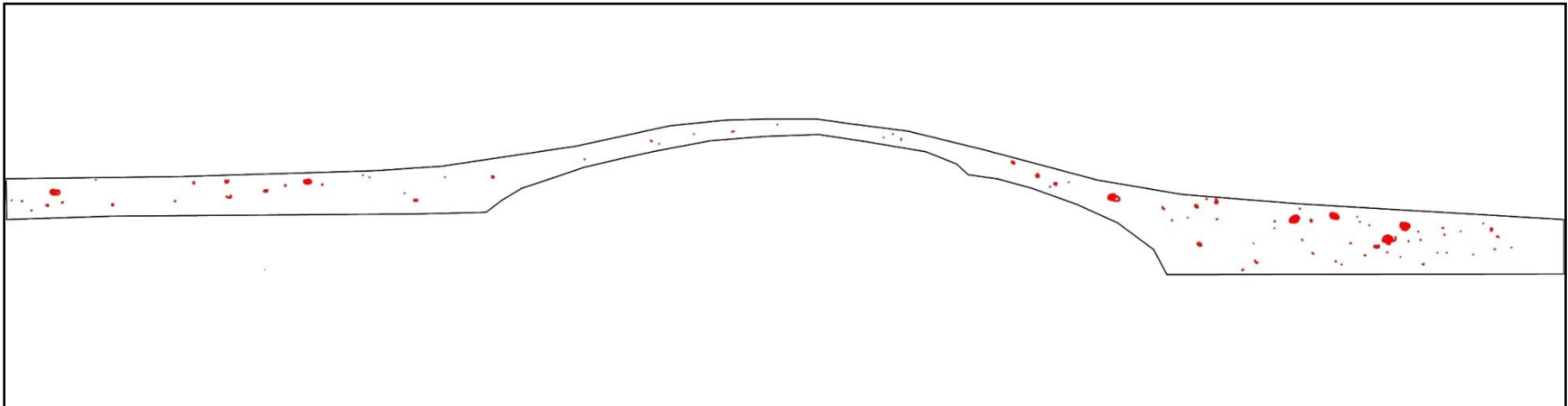


Figure 156: Schematic showing the coating area and the voids/bubbles in red of 2-part epoxy coating applied after 5 hour hold

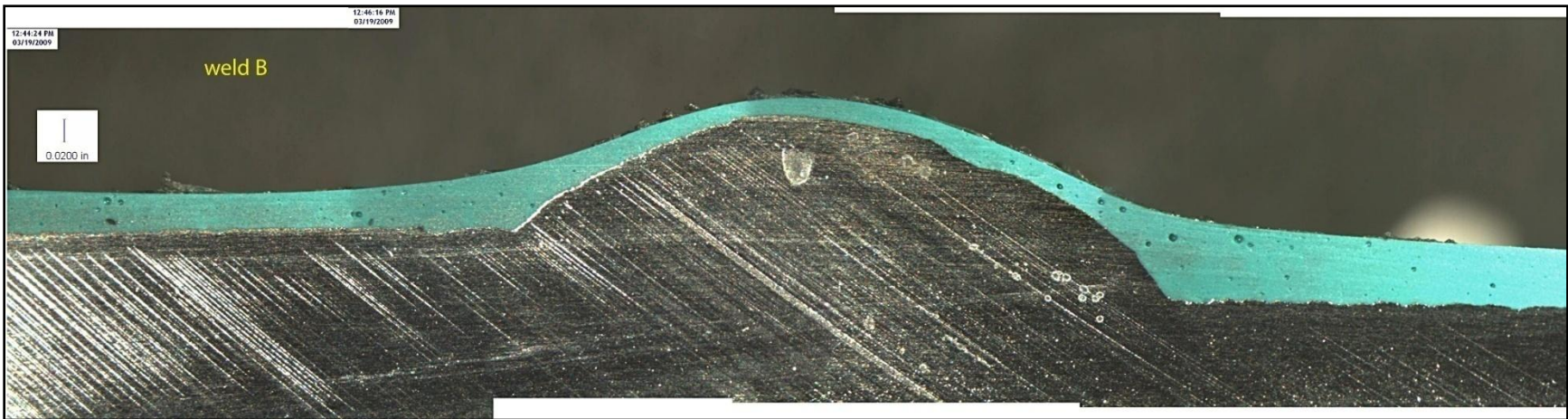


Figure 157: Cross-section image of the welded area of 2 -part epoxy coating applied after a preheat treatment

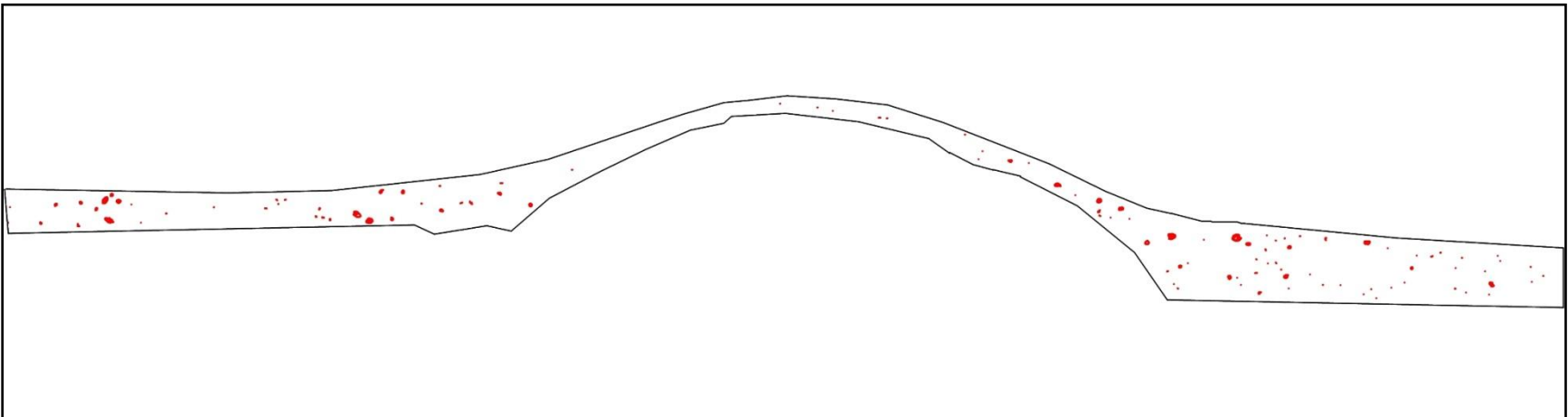


Figure 158: Schematic showing the coating area and the voids/bubbles in red of 2-part epoxy coating applied after preheat treatment

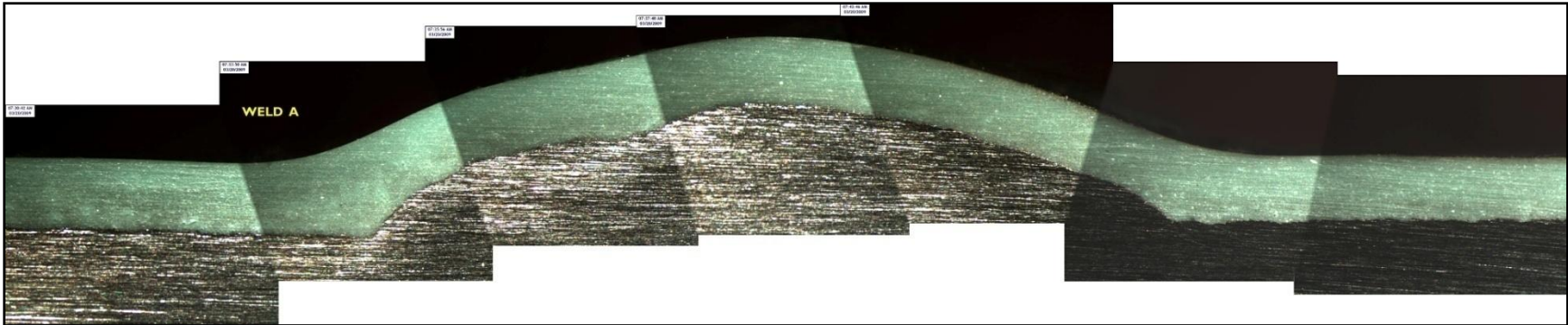


Figure 159: Cross-section image of the welded area of FBE coating applied after 2 hour hold



Figure 160: Schematic showing the coating area and the voids/bubbles in red of FBE coating applied after 2 hour hold

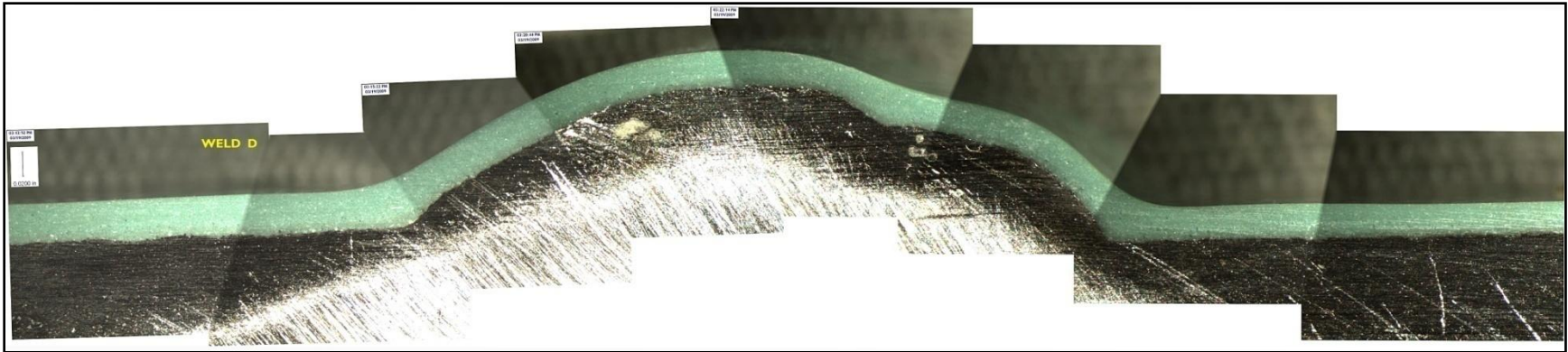


Figure 161: Cross-section image of the welded area of FBE coating applied after 5 hour hold

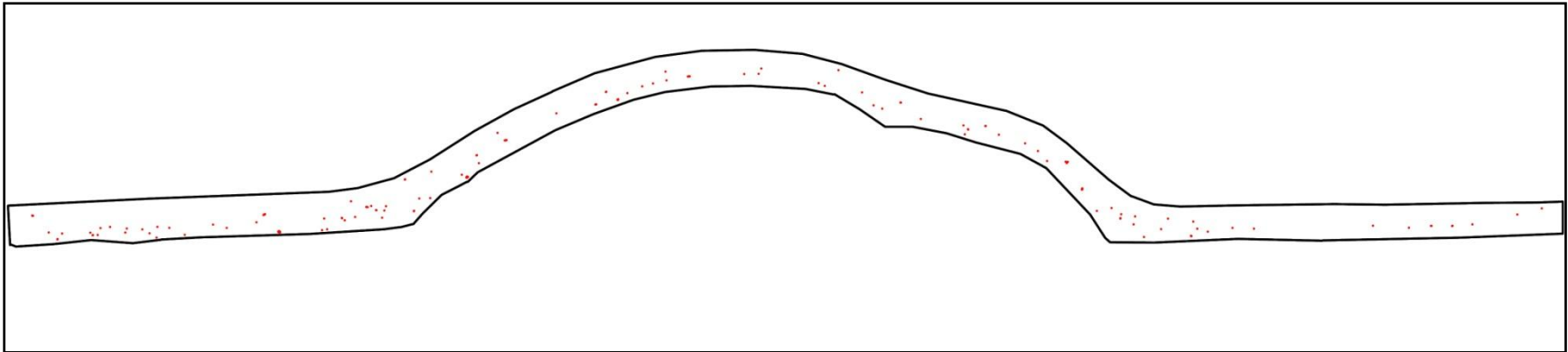


Figure 162: Schematic showing the coating area and the voids/bubbles in red of FBE coating applied after 5 hour hold

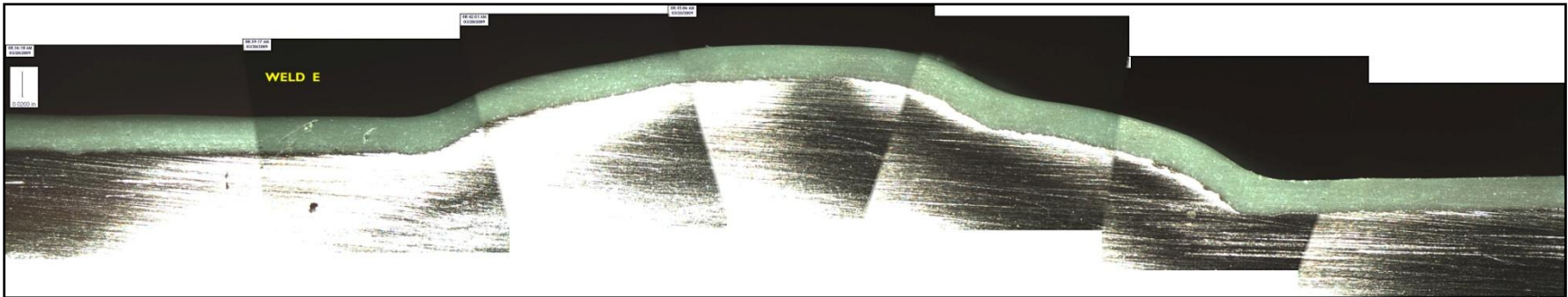


Figure 163: Cross-section image of the welded area of FBE coating applied after preheat treatment

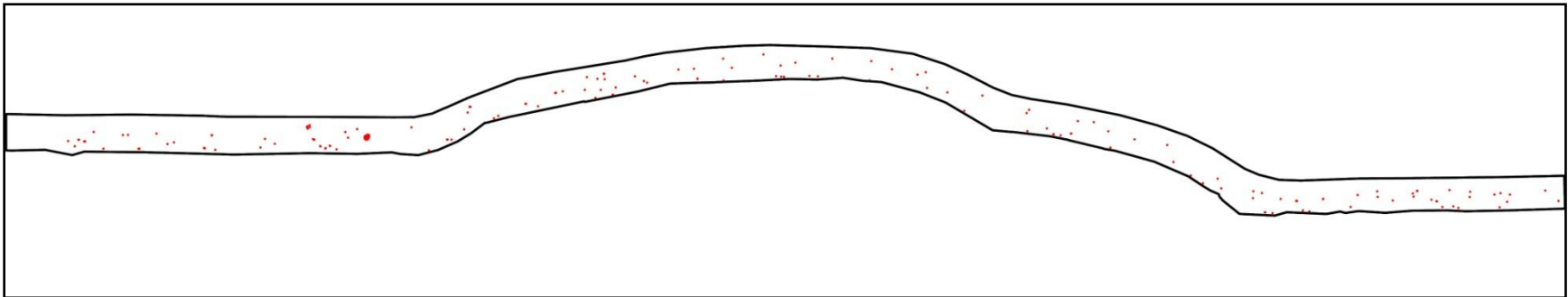


Figure 164: Schematic showing the coating area and the voids/bubbles in red of FBE coating applied after preheat treatment

9.4 Results from Cathodic Disbondment Testing – Images

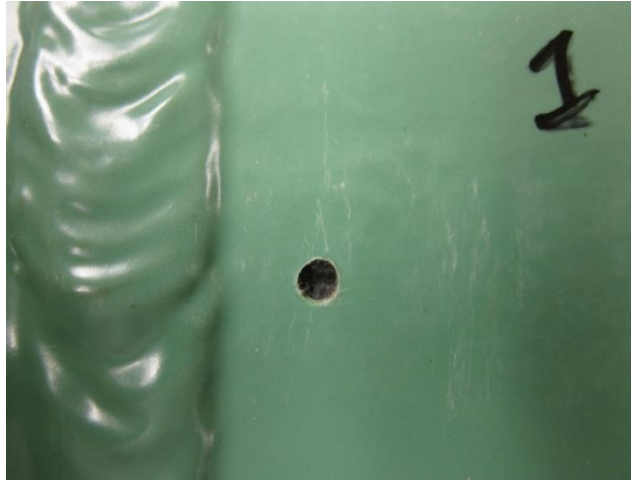


Figure 165: Post CD testing, 6 inch - FBE – 2 Hour hold time



Figure 166: Reference area, 6 inch - FBE – 2 Hour hold time



Figure 167: Post CD testing and picking, 6 inch - FBE – 2 Hour hold time



Figure 168: Post CD testing, 6 inch - FBE – 5 Hour hold time

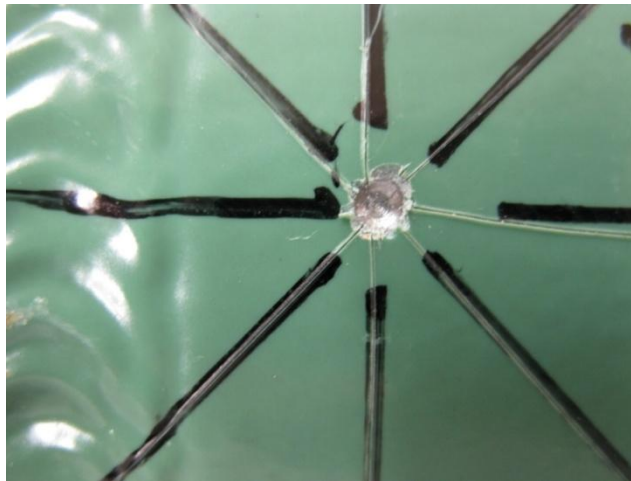


Figure 169: Reference area, 6 inch - FBE – 5 Hour hold time

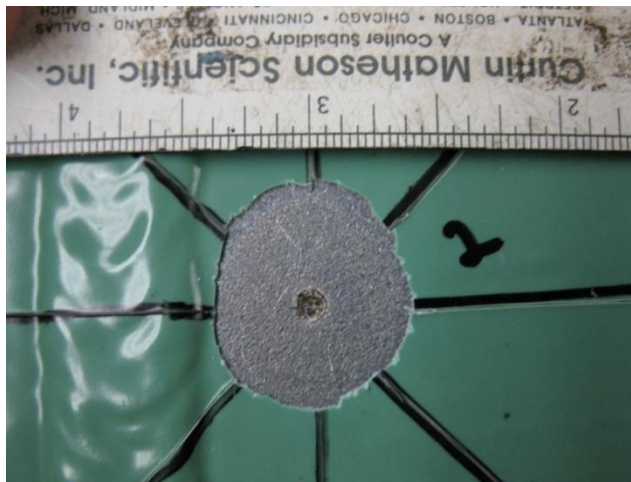


Figure 170: Post CD testing and picking, 6 inch - FBE – 5 Hour hold time

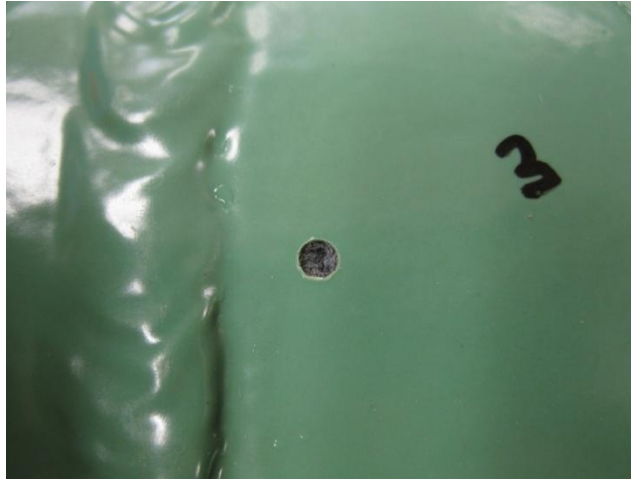


Figure 171: Post CD testing, 6 inch - FBE – Preheat

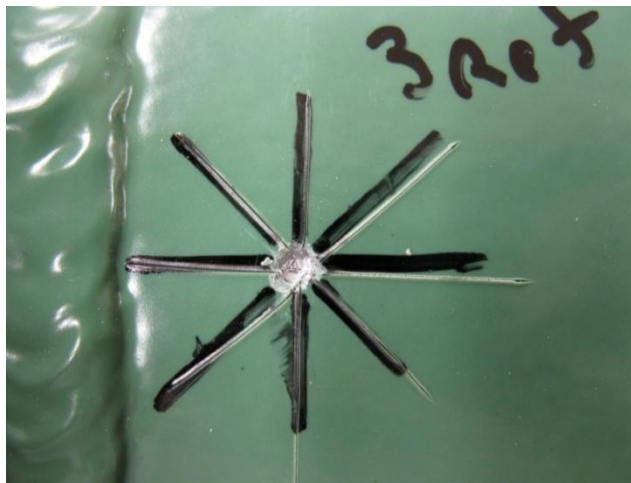


Figure 172: Reference area, 6 inch - FBE – Preheat

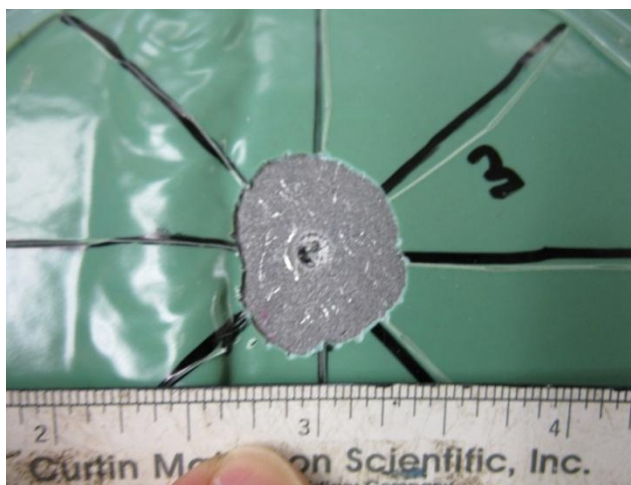


Figure 173: Post CD testing and picking, 6 inch - FBE – Preheat



Figure 174: Post CD testing, 6 inch - 2-Part Epoxy – 2 Hour hold time

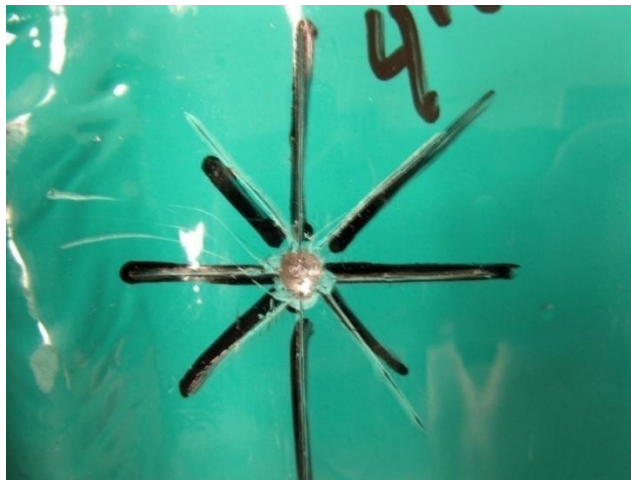


Figure 175: Reference area, 6 inch - 2-Part Epoxy – 2 Hour hold time



Figure 176: Post CD testing and picking, 6 inch - 2-Part Epoxy – 2 Hour hold time

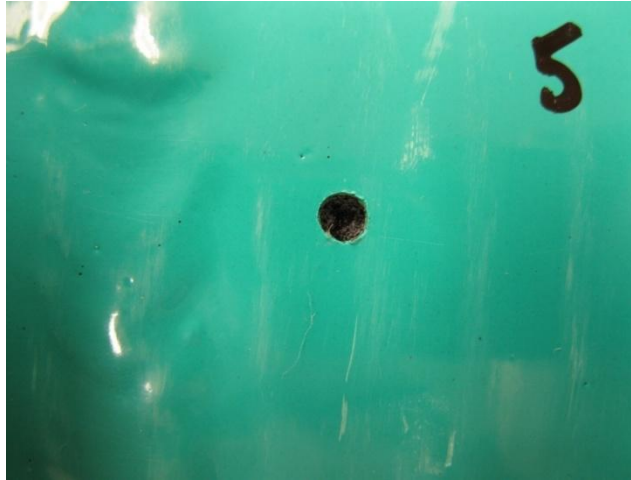


Figure 177: Post CD testing, 6 inch - 2-Part Epoxy – 5 Hour hold time



Figure 178: Reference area, 6 inch - 2-Part Epoxy – 5 Hour hold time



Figure 179: Post CD testing and picking, 6 inch - 2-Part Epoxy – 5 Hour hold time



Figure 180: Post CD testing, 6 inch - 2-Part Epoxy – Preheat



Figure 181: Reference area, 6 inch - 2-Part Epoxy – Preheat



Figure 182: Post CD testing and picking, 6 inch - 2-Part Epoxy – Preheat

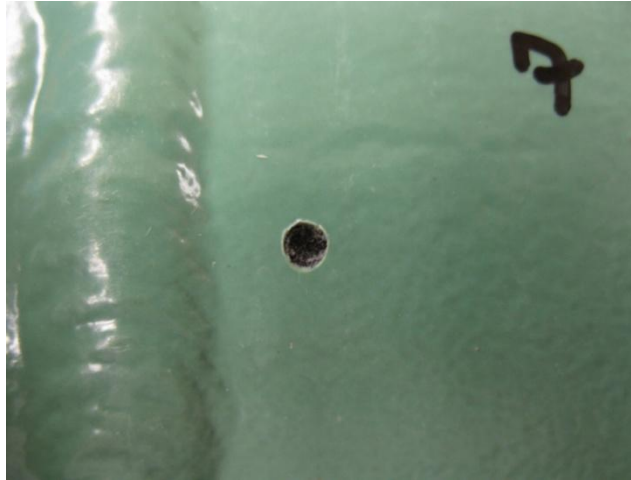


Figure 183: Post CD testing, Other Electrode: 6 inch - FBE – 2 Hour hold time

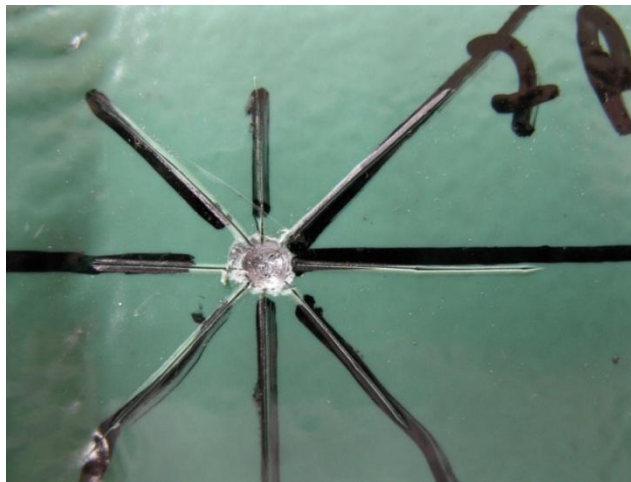


Figure 184: Reference area, Other Electrode: 6 inch - FBE – 2 Hour hold time

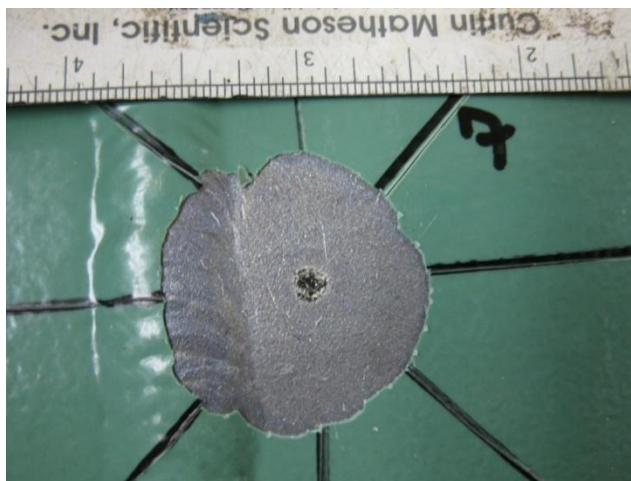


Figure 185: Post CD testing and picking, Other Electrode: 6 inch - FBE – 2 Hour hold time



Figure 186: Post CD testing, 24 inch - 2-Part Epoxy – Preheat



Figure 187: Reference area, 24 inch - 2-Part Epoxy – Preheat



Figure 188: Post CD testing and picking, 24 inch - 2-Part Epoxy – Preheat



Figure 189: Post CD testing, 24 inch - FBE – 5 Hour Hold

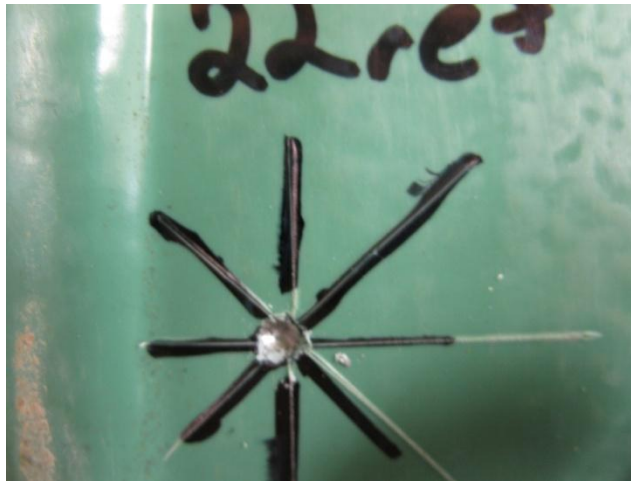


Figure 190: Reference area, 24 inch - FBE – 5 Hour Hold

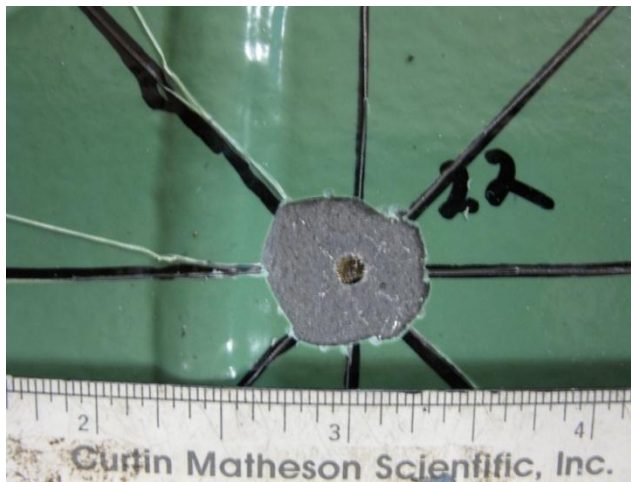


Figure 191: Post CD testing and picking, 24 inch - FBE – 5 Hour Hold



Figure 192: Post CD testing, 24 inch - 2-Part Epoxy – 5 Hour Hold

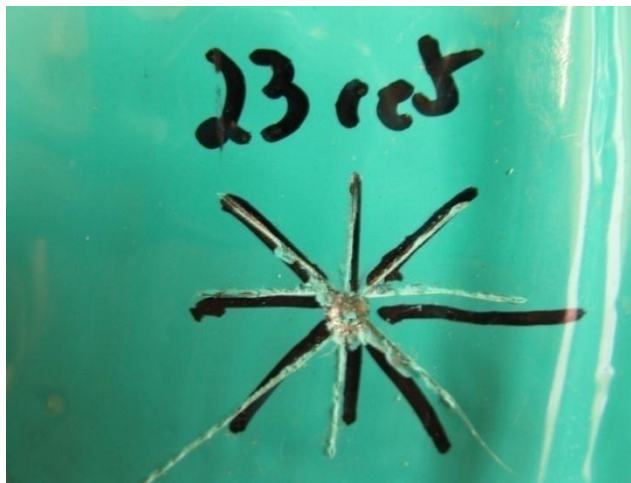


Figure 193: Reference area, 24 inch - 2-Part Epoxy – 5 Hour Hold

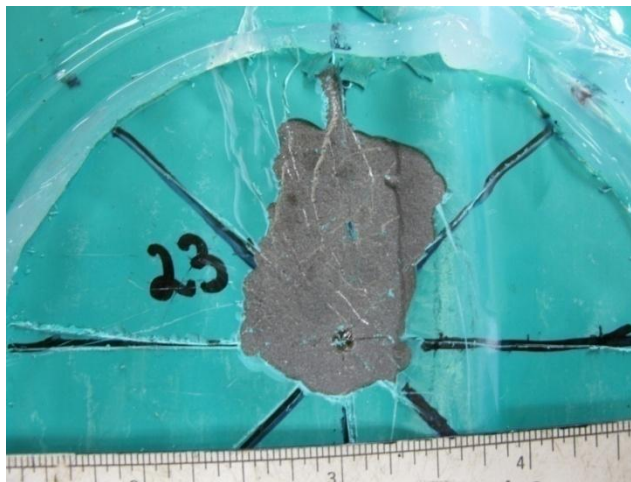


Figure 194: Post CD testing and picking, 24 inch - 2-Part Epoxy – 5 Hour Hold

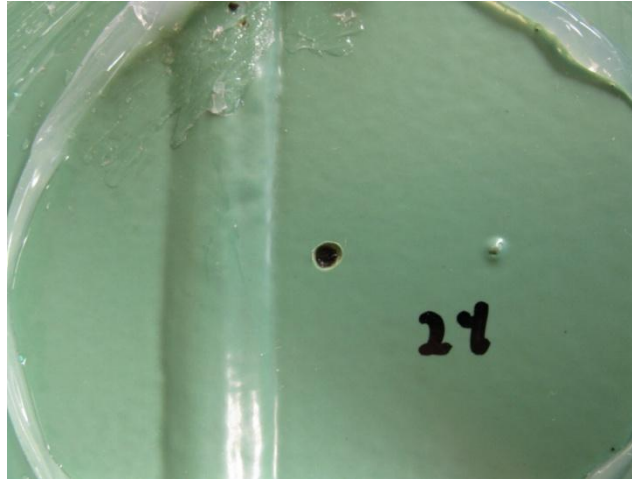


Figure 195: Post CD testing, 24 inch - FBE – Preheat

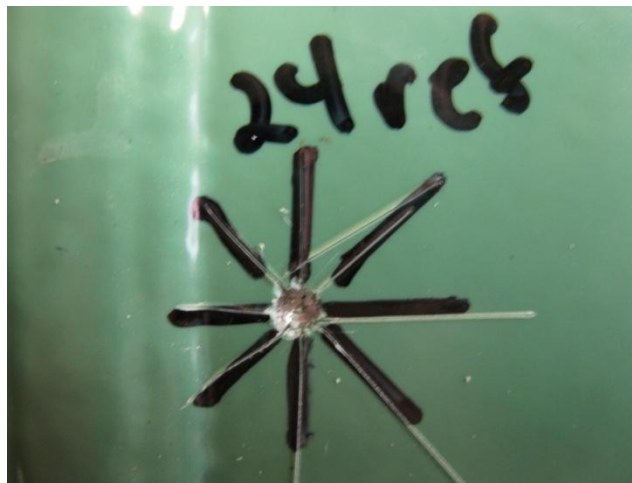


Figure 196: Reference area, 24 inch – FBE – Preheat



Figure 197: Post CD testing and picking, 24 inch - FBE – Preheat



Figure 198: Post CD testing, 24 inch - 2-Part Epoxy – 2Hour Hold



Figure 199: Reference area, 24 inch - 2-Part Epoxy – 2 Hour Hold



Figure 200: Post CD testing and picking, 24 inch - 2-Part Epoxy – 2 Hour Hold

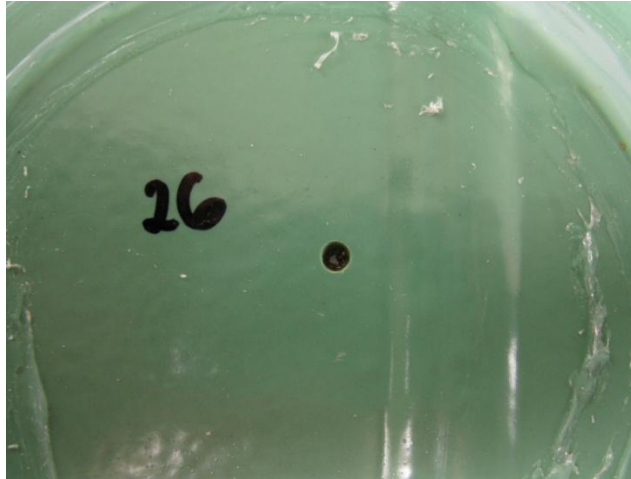


Figure 201: Post CD testing, 24 inch - FBE – 2 Hour Hold



Figure 202: Reference area, 24 inch - FBE – 2 Hour Hold



Figure 203: Post CD testing and picking, 24 inch - FBE – 2 Hour Hold

References

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- ³ ASME B31.8 Gas Transmission Distribution and Piping Systems, American Society of Mechanical Engineers, 2003.
- ⁴ ANSI/AWS D1.1/D1.1M Structural Welding Code: Steel, American Welding Society, 2006.
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- ⁷ National Electrical Manufacturers Association, *EW 1, Electric Arc Welding Power Sources* (Washington: National Electrical Manufacturers Association, 1988), 3.
- ⁸ American Welding Society (AWS), *Welding Handbook, 8th Edition, Volume 1, Welding Technology* (Miami: American Welding Society, 1987), 447.
- ⁹ American Welding Society (AWS), *Welding Handbook, 8th Edition, Volume 1, Welding Technology* (Miami: American Welding Society, 1987), 581.
- ¹⁰ The James F. Lincoln Arc Welding Foundation, *Principles of Industrial Welding* (Cleveland: The James F. Lincoln Arc Welding Foundation, 1978), 12-28.
- ¹¹ February 5, 2007 Email from Joe Kiefer of ConocoPhillips.

End of Report